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PHYSICAL MEASUREMENTS OF AUDITION AND THEIR BEARING ON THE THEORY OF HEARING.*

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THE question of how we hear has been a subject for discussion by scientists and philosophers for a long time. Practically every year during the past fifty years articles have appeared discussing the pros and cons of various theories of hearing. These discussions have been participated in by men from the various branches of science and particularly by the psychologists, physiologists, otologists, and physicists. During the past two or three years this discussion has been particularly acute. It is not uncommon to pick up an article and read in the beginning or concluding paragraphs statements such as the Helmholtz theory of audition seems to have sunk beyond recovery, [90, 65] † and at the same time an article written probably a month later will have the conclusion that the Helmholtz theory of audition is definitely established beyond all controversy.[70-75]

There is apparently a great deal of misunderstanding between various writers because of different points of view due to different training. To the physicist it seems that most of the discus-

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† These numbers refer to the bibliography at the end of the paper.

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sions show a profound ignorance of the dynamics of the transmission of sound by the mechanism of the ear. Those discussions by the physicists are frequently open to criticism by the otologist and psychologist, due to his lack of knowledge of the structure of the ear or the mental reaction involved in the process of interpretation. I think it is fortunate that some of these scientists from the different branches are now coöperating in their research work as is evinced by the appearance of several joint papers. (Papers by Dean and Bunch, Minton and Wilson, Wegel and Fowler, Kranz and Pohlman, and others.)

It is not my purpose to discuss the merits of the various theories of hearing, but I desire to present some of the facts of audition which have been recently determined with considerable accuracy, and then discuss the theory of hearing which best explains these facts.

Hearing is one of the five senses. It is that sense that makes us aware of the presence of physical disturbances called sound waves. For my purpose, sounds may be classified into two groups, namely, pure tones and complex sounds. A pure tone is specified psychologically by two properties, namely, the pitch and the loudness. These sensory properties are directly related to the physical properties, frequency and intensity of vibration. Mixtures of pure tones of different loudness, but of the same pitch, fall under the first class, since such mixtures give rise to a pure tone. The complex sounds are varying mixtures of pure tones. It will be noticed that phase has not been taken into account. Except when using the two ears for locating the direction of sources of sound, phase differences are not ordinarily appreciated by the ear.*

These tones are usually transmitted by means of air waves through the outer ear canal to the drum of the ear. From here the vibrations are transmitted by means of the bones in the middle ear to the mechanism of the inner ear.

Those facts of audition which are familiar to almost everybody are as follows:

* This statement may require modification when more experimental data are available. As shown later in the paper the middle ear has a non-linear response. Consequently it would be expected that phase differences, especially between tones which are harmonic, would produce spacial differences in nerve stimulation.

1. Pure tones are sensed by the ear and differentiated by means of the properties *pitch* and *loudness*.

2. When two notes, separated by a musical interval, are sounded together, they are sensed as two separate notes. They would never be taken for a tone having the intermediate pitch. In this respect, hearing is radically different from seeing. When a red and a green light are mixed together, the impression received by the eye is that of yellow, an intermediate color between the two.

3. There is a definite limiting difference in pitch that can just be sensed.[1-9]

4. There is a definite limiting difference in intensity that can just be sensed.[10-14]

5. There is a minimum intensity of sound below which there is no sensation.[15-31]

6. There is an upper limit on the pitch scale above which no auditory sensation is produced.[32-44]

7. There is a lower limit on the pitch scale below which there is no auditory sensation produced.[45-51]

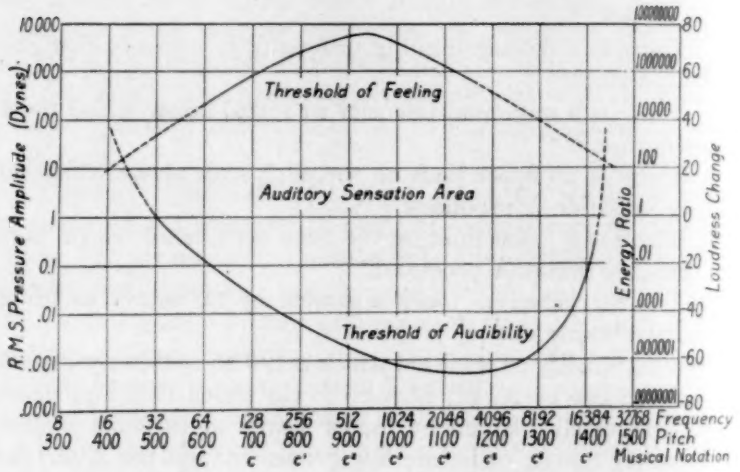
8. The ear perceives tones separated by an octave as being very similar sensations.

Another quality of audition which is not so commonly known was pointed out by A. M. Mayer.[52] He stated that high tones can be completely masked by louder lower tones while intense higher tones cannot obliterate lower ones though the latter are very weak. Experiments to be described later in the paper show that this statement must be modified somewhat. Very intense low ones will produce a masking effect upon still lower tones, although the masking effect is very much more pronounced in the opposite case. Many of the opponents of the Helmholtz resonant theory of hearing claim that this fact is fatal to such a theory.[52]

The new tools which have made possible more accurate measurements in audition are the vacuum tube, the thermal receiver and the condenser transmitter. When connected in a proper arrangement of circuits, the vacuum tube is capable of generating an oscillating electrical current of any desired frequency. This electrical vibration is translated into a sound vibration by means of the telephone receiver. Between the receiver and the oscillator, a wire network called an attenuator [28] is interposed which makes

it possible to regulate the volume of sound. The theory [54-55] of the thermal receiver has been worked out so that it is possible to calculate its acoustic output from the electrical energy it is absorbing. In this way, it is possible to calculate the pressure variation produced in the outer ear canal when a tone is being perceived. A detailed description of the apparatus and method used in such measurements was given in a paper presented before the National Academy of Science, November 14, 1921.[55] Such

FIG. 1.



a combination of apparatus which has been calibrated is called an audiometer and is suitable for measuring abnormal as well as normal hearing. A receiver more rugged than the thermal may be substituted when its efficiency compared to the thermal receiver is known for all frequencies. By using such an audiometer, the average absolute sensitivity for approximately 100 ears which were considered to be normal was determined. The lower curve in Fig. 1, labelled the threshold of audibility, shows the results of such measurements. The ordinates give the amplitude of the pressure variation in dynes per square centimetre that is just sufficient to cause an auditory sensation and the abscissæ give the frequency of vibration of the tone being perceived. Both are plotted on a logarithmic scale. The experimental difficulties made it impossible to make a very accurate determination for

those parts of the curve shown by dotted lines. More work needs to be done on these portions of the curve. In the important speech range, namely, from 500 to 5000 cycles, it requires approximately .001 of a dyne pressure variation in the air to cause an auditory sensation. This corresponds to a fractional change of about one-billionth in the atmospheric pressure, which shows the extreme sensitiveness of the hearing mechanism.

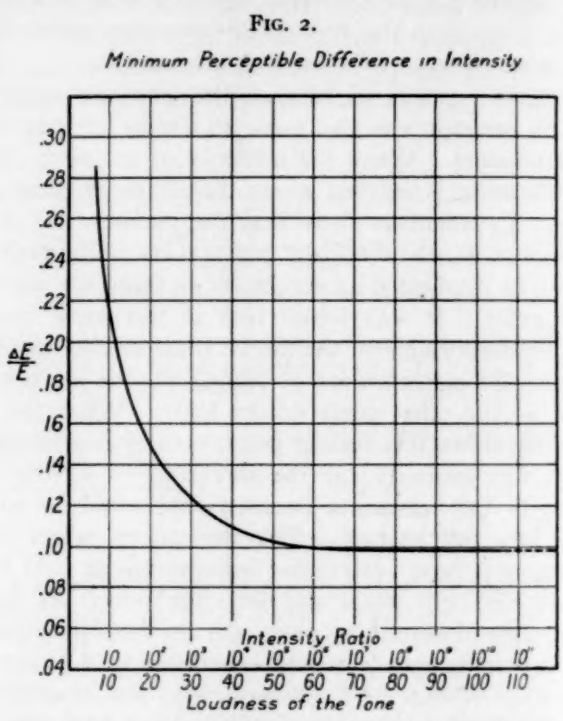
In order to obtain an idea of the intensity range used in hearing, an attempt was also made to obtain an upper limit for audible intensities. When the intensity of a tone is continually increased, a value is reached where the ear experiences a tickling sensation. Experiments show that the intensity for this sensation is approximately the same for various individuals and the results can be duplicated as accurately as those for the minimum intensity value. It was found that if this same intensity of sound is impressed against the finger, it excites the tactile nerves. In other words, the sensation of feeling for the ear is practically the same as for other parts of the body. When the intensity goes slightly above this feeling point, pain is experienced. Consequently, this intensity for the threshold of feeling was considered to be the maximum intensity that could be used in any practical way for hearing. The two points where these two curves intersect have interesting interpretations. At these two points, the ear both hears and feels the tone. At frequencies above the upper intersecting point, the ear feels the sound before hearing it, and in general would experience pain before exciting the sensation of hearing. Consequently, the intersection point may be considered as the upper limit in pitch which can be sensed. In a similar way, the lower intersection point represents the lowest pitch that can be sensed.

There has been considerable work[32-51] in the past to determine the upper frequency and lower frequency limits of audibility, but it would appear that without the criterion just mentioned, such limiting points apply only to the particular intensity used in the determination. Not enough attention has been paid to the intensity of the tones for such determinations. It is quite evident from this figure that both the upper and lower limits of audibility which are found in any particular experimental investigation will very largely depend upon the intensity of the tones sounded.

For example, if the intensity were along the .01 dyne line, the limits would be 200 and 12,600 cycles.

The area enclosed between the maximum and minimum audibility curves has been called the auditory-sensation area and each

FIG. 2.



point in it represents a pure tone. The question then arises: How many such pure tones can be sensed by the normal ear?

The answer to this question has been made possible by the recent work of Mr. V. O. Knudsen.[14] In this work Knudsen made determinations of the sensibility of the ear for small differences in pitch and intensity. In Fig. 2, the average results of his measurements for changes in intensity are shown. Each ordinate gives the fractional change in the sound energy which is just perceptible, this fractional change being called the Fechner ratio. The abscissæ are equal to ten times the logarithm of the ratio of intensities, the zero corresponding to the intensity at the threshold of audibility. For intensities greater than 10^4 times the

threshold of audibility, the Fechner ratio has the constant value of approximately one-tenth. It was found that this ratio is approximately the same for all frequencies. In Fig. 3 is shown the results taken from Knudsen's article on the pitch sensibility. The ordinates give the fractional change in the frequency which is just perceptible and the abscissæ give the frequency on a logarithmic scale. The meaning of the pitch scale at the bottom of this

FIG. 3.

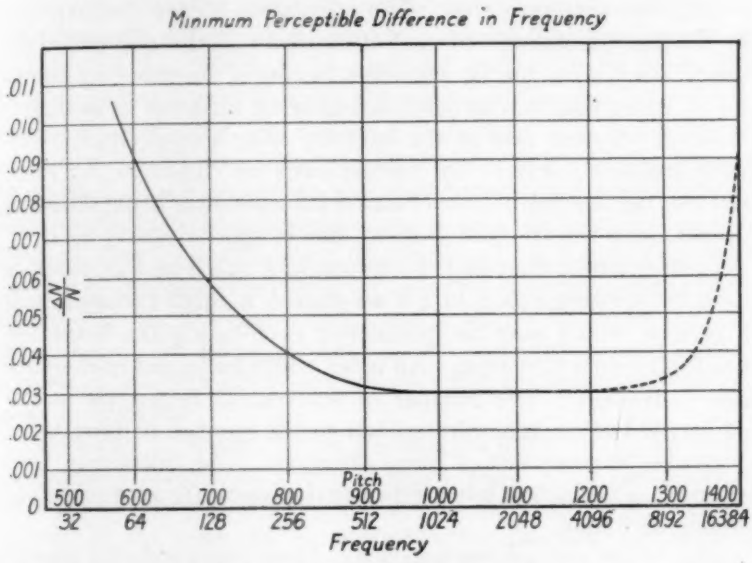


figure will be discussed later. For frequencies above 400 this fractional change is a constant equal to .003. This ratio probably becomes larger again for the very high frequencies. It was found that it varied with intensity in approximately the same way as that given for the energy ratio.

Using these values in connection with the auditory-sensation area, it it possible to calculate the number of pure tones which the ear can perceive as being different. For example, if, starting at the minimum audibility curve, ordinate increments are laid off along a constant pitch line, that are successively equal to the value of ΔE at the intensity position above the threshold, then the number of such increments between the upper and lower curves in Fig.

1 is equal to the number of pure tones of constant pitch that can be perceived as being different in volume. If the minimum and maximum audibility curves were plotted on an energy scale, the increment length ΔE near the maximum audibility curve would be a million million times longer than its length in the minimum audibility curve, whereas when they are plotted on a logarithmic scale, this increment length remains approximately constant, changing by less than a factor 2 for 90 per cent. of the distance across the auditory-sensation area. The calculation shows (see Appendix A) that the number of such increments on the 100-cycle frequency line is 270, that is, 270 tones having a frequency of vibration of 1000 cycles can be perceived as being different in loudness.

What has been said of the intensity scale applies equally well to the frequency scale. The calculation (see Appendix A) indicates that the number of tones that are perceivable as being different in pitch along the 10-dyne pressure line is approximately 1300.

If an ordinate increment corresponding to ΔE and an abscissa increment corresponding to ΔN be drawn, a small rectangle will be formed which may be considered as forming the boundary lines for a single pure tone. All tones which lie in this area sound alike to the ear. The number of such small rectangles in the auditory-sensation area corresponds to the number of pure tones which can be perceived as being different. The calculation (see Appendix A) of this number indicates that there are approximately 300,000 such tones.

One might well ask the question: How many complex sounds which are different can be sensed by the ear? At first thought, one might say that this number is represented by all the possible combinations of pure tones. Of course, such a number would be entirely too large, for some of these would sound alike to the ear, since the louder tones would necessarily mask the feebler ones. It is evident, however, that the number of such complex sounds will be very much larger than the number of pure tones.

It is seen that the use of the logarithmic scale in Fig. 1 is much more convenient not only on account of the large range of values necessary to represent the auditory-sensation area, but also because of its scientific basis. Psychologists have recognized this since Weber and Fechner formulated the relation between the sensation and the stimulus. Although logarithmic units have

been used by various authors in measuring the amount of sensation, the numerical values have been quite different. It seems inevitable that there will be a greater coöperation in the future between men in the various branches of science working on this subject, so, in order to avoid misunderstanding, it would be very advantageous for all to use, as far as possible, the same units. With this in mind, I am taking the liberty of suggesting for discussion units for both loudness and pitch.

In the telephone business, the commodity being delivered to the customers is reproduced speech. One of the most important qualities of this speech is its loudness, so it is very reasonable to use a sensation scale to define the volume of the speech delivered. At the present time, an endeavor is being made to obtain an agreement of all the telephone companies, both in the United States and abroad, to adopt a standard logarithmic unit for defining the efficiency of telephone circuits and the electrical speech levels at various points along the transmission lines. The *chief interest* in changes in efficiency of transmission apparatus is their effects upon the loudness of the speech delivered by the receiver at the end of the telephone circuit. So it would be very advantageous to use this same logarithmic scale for measuring differences in loudness.

This scale is chosen so that the loudness difference is ten times the common logarithm of the intensity ratio. This means that if the intensity is multiplied by a factor 10, the loudness is increased by ten; if the intensity is multiplied by 100, the loudness is increased by 20; if the intensity is multiplied by 1000, the loudness is increased by 30, etc. It was seen above that under the most favorable circumstances a change in loudness equal to $1/2$ on this scale could just be detected. Knudsen's data indicates, however, that when a silent interval of only two seconds intervenes between the two tones being compared, a loudness change greater than unity on this scale is required before it is noticeable. So the smallest loudness change that is ordinarily appreciated is equivalent to one unit on this scale. It is also convenient because of the decimal relation between loudness change and intensity ratio. This relation is expressed by the formula:

$$\Delta L = L_1 - L_2 = 10 \log_{10} \frac{I_1}{I_2} \text{ or } \frac{I_1}{I_2} = 10^{\frac{\Delta L}{10}}$$

where L_1 and L_2 are the two loudness values corresponding to the intensities I_1 and I_2. Since intensities of sound are proportional to the square of pressure amplitudes this may also be written:

$$\Delta L = 20 \log \frac{p_1}{p_2}$$

The most convenient choice of the intensity or pressure used as a standard for comparison depends upon the problem under consideration. In the sensation area chart of Fig. 1, the intensity line corresponding to one dyne was used as the zero level, that is, p_2 was chosen equal to 1 so that

$$\Delta L = 20 \log p$$

The choice of the base of logarithms for the pitch scale is dictated by the fact mentioned before, that the ear perceives octaves as being very similar sensations. Consequently the base 2 is the most logical choice for expressing pitch changes. If the logarithm of the frequency to the base 2 were used, perceptible changes in pitch would correspond to inconveniently small values of the logarithm. It is better to use the logarithm to the base $\sqrt[100]{2}$ which is 100 times as large. On this scale the smallest perceptible difference in pitch is approximately unity—somewhat more for frequencies greater than 100 cycles or somewhat less for lower frequencies, according to Knudsen's data. The scale on the charts is chosen so that the change in pitch is given by

$$\Delta P = 100 \log_2 N$$

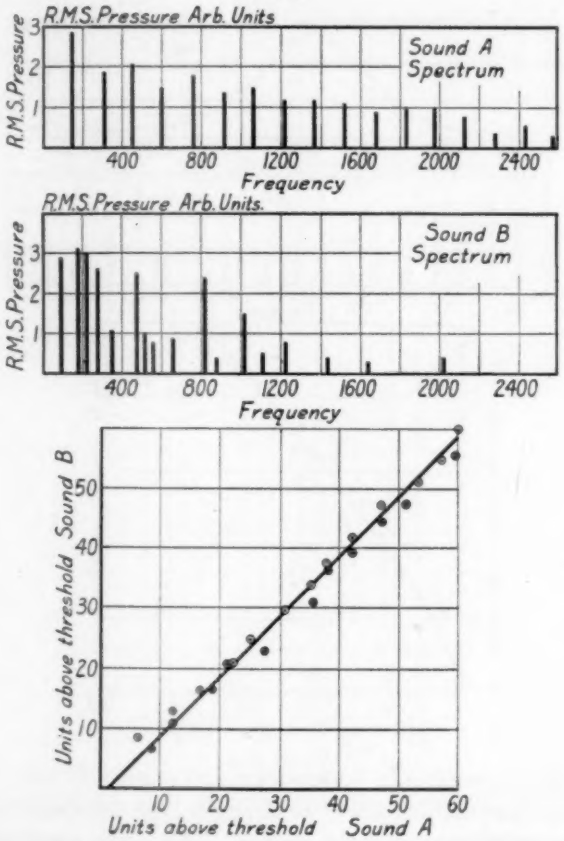
where N is the frequency of vibration.

It is now evident why such pitch and loudness scales were used in Fig. 1. With these scales, the number of units in any area gives approximately the number of tones that can be ordinarily appreciated in that area. For example, there are approximately 2000 distinguishable tones in each square, there being more near the centre and fewer near the boundary lines than this number.

Experiments have shown that pure tones of different frequencies which are an equal number of units above the threshold value sound equally loud. This statement may require modification when very loud tones are compared, but the data indicated that throughout the most practical range this was true. Consequently, the absolute loudness of any tone can be taken as the number of units above the threshold value.

In the measurement of the loudness of complex tones, the situation is not so simple. It has been found that if two complex tones are judged equally loud at one intensity level and then each is magnified equal amounts in intensity, they then may or may not sound equally loud. The curves shown in Figs. 4, 5 and 6

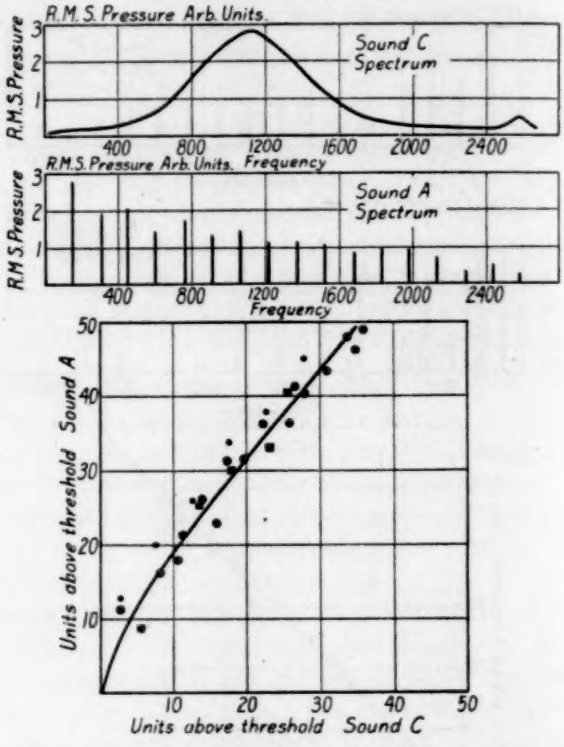
FIG. 4.



will illustrate this. The first (Fig. 4) shows the comparisons at different intensity levels of two sounds whose pressure spectra are shown in the two figures at the top. The x-axis gives units above threshold for sound A and the y-axis gives the units above threshold of the sound B when the two sound equally loud. In this case, the spectra are somewhat similar and we have a straight

line of slope 45° passing nearly through the origin. The two sounds are thus of practically equal loudness when they are the same number of units above threshold. In Fig. 5 we have similar data for two sounds which have quite different spectra as is indicated by the two charts at the top. The curve for *C* means

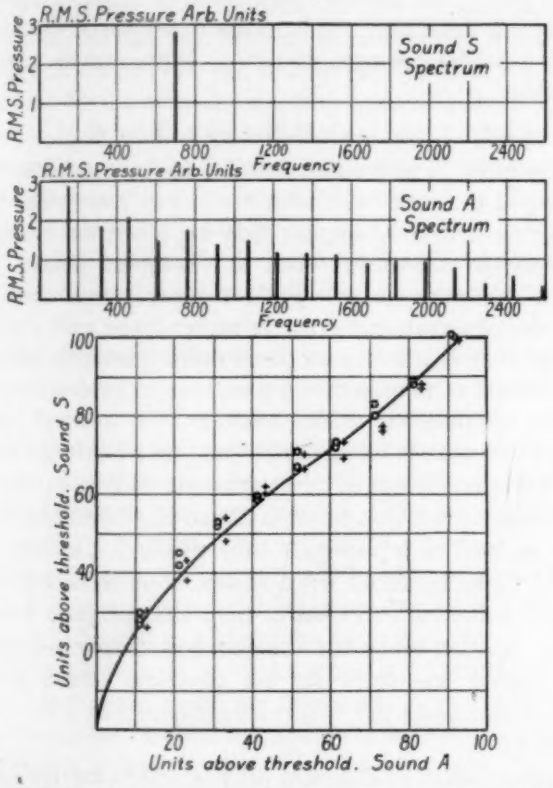
FIG. 5.



that it was a practically continuous spectrum. It was produced by a device for making the "swishing" type of noises which are usually so prominent in office rooms. The curve representing the relation is not straight, since for values of intensity near the threshold, the loudness increases faster for the *C* sound for increments in the intensity than for the *A* sound. For example it is seen that when the sound *C* is 30 units above the threshold, the sound *A* is 45 units above the threshold when the two sound equally loud. In Fig. 6 a comparison is given between the loud-

ness of a pure tone of 700 cycles and a complex sound designated by *A* in the last figure. In this case again the relation is expressed by a curve. The technic of making such loudness measurements is rather difficult and requires a large number of observations before the values are reliable. A paper on this subject which will

FIG. 6.



soon be published will give a detailed account of this work on loudness.

Enough data have been given to show that in order to give loudness a definite meaning for complex sounds, a more precise definition is necessary. It has been found convenient to define the loudness of any complex or pure tone in terms of the loudness of a sound standard. This standard is a pure tone having a vibration frequency of 700 cycles per second. Its abso-

lute loudness is defined as the change in loudness measured on the scale defined above, from the loudness value corresponding to the threshold pressure for normal ears which for 700 cycles is exactly 0.001 dyne. This frequency was arbitrarily chosen as a standard for measuring loudness because of this particular value of its threshold pressure, and because it is close to the frequency at which the loudest tones used in conversational speech occur. By this definition, the loudness of a tone of frequency 700, for which p is the pressure variation, expressed as a root mean square value,

$$L = 60 + 20 \log p$$

and the loudness of any other sound, pure or complex, is defined as being equal to that of a tone of frequency 700, seeming equally loud. Such a definition implies that experimental measurements can be made to determine when any complex sound is equally loud to a 700-cycle tone. Such measurements can be made although the observational error is rather large and the judgment of various individuals is sometimes quite different, which means only that loudness as measured by various individuals is different. For use in engineering work, however, the average of a large number of individuals can be taken and this loudness will have a definite determinable value. For example in Fig. 6, the loudness of the A sound when it is 60 units above the threshold is 72, since it sounds as loud as a 700-cycle tone which is 72 units above its threshold. The loudness of complex sounds usually increases faster with increases in intensity than that of pure tones. This would be expected since the threshold is determined principally by the loudest frequency in the complex sound and as the intensity is increased the other frequencies begin to add to the total loudness.

Since pure tones of different pitches which are the same number of units above the threshold sound equally loud their loudness L can be represented by the formula

$$L = L_0 + 20 \log p$$

where p is the root mean square value of the pressure amplitude produced in the ear by the tone and L_0 is the number of units from the 1-dyne line to the minimum audibility curve. The values of L_0 can be read directly from the chart in Fig. 1.

The choice of the loudness and pitch units used above leads to a *rational definition of the degree of deafness.*

The number of possible pure tones that can be sensed by a deaf person is considerably smaller than that mentioned above obtained from the normal auditory-sensation area. A logical way of defining the amount of hearing is: *To give the per cent. of the total number of distinguishable pure tones audible to a person with normal hearing, that can be sensed by the deaf person.*

Some definition of this sort will be very helpful in clearing up the confusion that now exists in court cases involving the degree of deafness. It is well known that there are a number of laws which prevent people who have more than a defined amount of deafness from doing certain classes of work. For example, one cannot operate an automobile if he has a certain per cent. of deafness. At the present time, there is a large variation between the standards set up by the various doctors in different parts of the country.

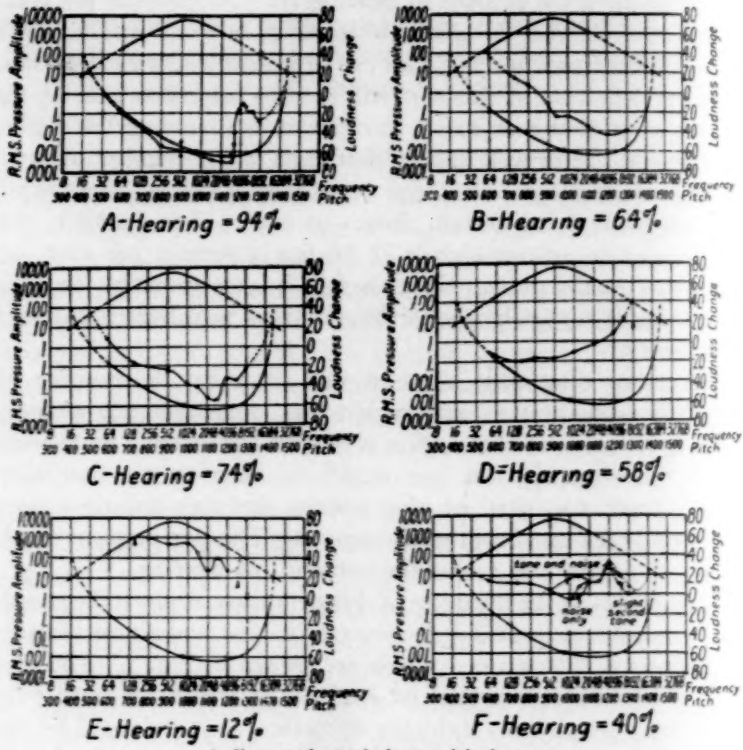
From the discussion above it was seen that the number of tones corresponding to any region was approximately proportional to the area of that region when the logarithmic units were used. Consequently the per cent.* of hearing can be taken as the fractional part of the normal auditory-sensation area in which tones can be properly sensed. The per cent. of deafness is of course 100 minus the per cent. of hearing.

To emphasize the meaning of this definition, some audiograms, that is minimum audible intensity curves, for some typical cases of deafness will be given. These are shown in Fig. 7. The first chart shows a common type of deafness in which the sensitivity to the high frequencies suddenly decreases, as is indicated by the rise in the minimum audible intensity curve when the frequency exceeds 3000 cycles per second. The sensation area for this person is 94 per cent. of that for the average. Consequently, his per cent. of hearing is 94 per cent. It is also convenient to speak of the per cent. of hearing for each pitch. It is evident that the logical definition for this is the ratio of the widths of the sensation area for the person tested and normal person, measured along the ordinate drawn at the frequency in question.[56] For

* This assumes that the Fechner ratio for pitch and loudness is approximately the same for one having abnormal as for one having normal hearing.

example, in this audiogram the person had more than 100 per cent. hearing for most of the pitch range. At 4000 cycles, however, the per cent. hearing was only 60 per cent. This means that for this pitch, the person when compared with one having nor-

FIG. 7.



Audiograms for typical cases of deafness.

mal hearing could sense only 60 per cent. as many gradations in tonal volume before reaching the threshold of feeling.

The second chart corresponds to a type of deafness that is not so common. It shows relatively large losses at the lower frequencies. The per cent. hearing in this case is seen to be 64 per cent.

The third type is very common and corresponds to a general lowering of the frequencies throughout the entire pitch range. In these first three cases, the deaf persons could carry on a con-

versation without any difficulty whatever. In the last two of these, difficulty was experienced in understanding a speaker at any considerable distance. In the first case, the person could not hear the steam issuing from a jet or any other high hissing sound. However, he could hear and understand speech practically as well as anyone with normal hearing.

The fourth case shows a falling off at the high frequencies, but this loss in hearing proceeds gradually as the pitch increases rather than abruptly as in the first case. As indicated in the figure the per cent. of hearing is 58 per cent.

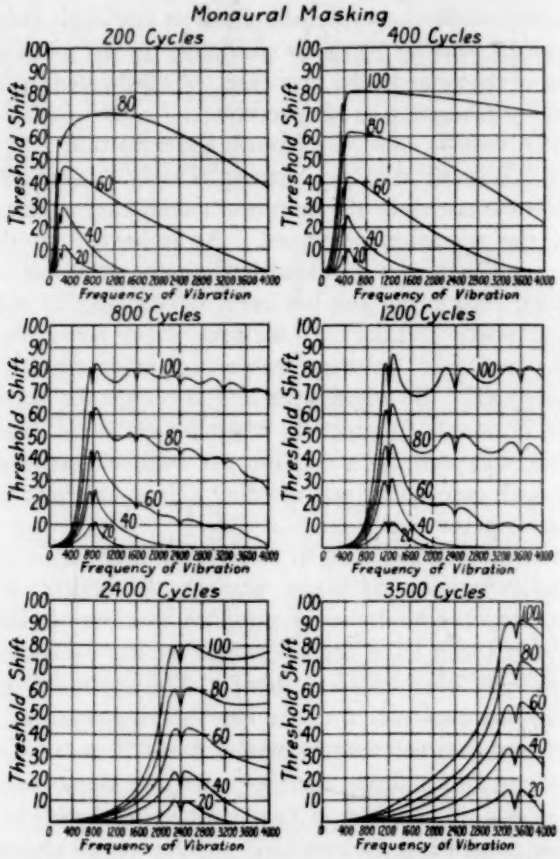
The fifth case is one of extreme deafness and is typical of such cases. The per cent. of hearing is only 12 per cent. The last case shows not only the minimum audibility curve, but the quality of the sensation perceived. As indicated on the chart, in certain regions noises are heard when the stimulus is a pure tone. When computing the per cent. of hearing in such cases, it seems reasonable to take only the area where sensation of good quality is perceived. In some cases, this poor quality extends through practically the whole area and although the person hears sounds, he is unable to properly interpret them. Consequently, from a practical point of view, his per cent. of hearing is very low. For such cases, deaf sets or other aids to the hearing do not give any satisfactory help.

We are now in a position to discuss another set of facts concerning the perception of tones, namely, the ability of the ear to perceive certain sounds in the presence of other sounds. Such data for pure tones have been obtained in our laboratories and will soon be published in some detail. The apparatus used consisted simply of two vacuum tube oscillators generating the two tones used and two attenuators which made it possible to introduce the tones into a single receiver with any desired intensities. In other words, it consists of two audiometers with a common receiver for generating the two tones. The curves shown in Fig. 8 give the general character of the results of this work.

The ordinates show the amounts in loudness units that the threshold value of a tone of any given frequency called the "masked tone" is shifted due to the presence of another tone called the "masking tone." The frequency of the masking tone is given at the top of each set of curves.

The experimental procedure was as follows: The threshold values for the two tones were first determined. The intensity of the masking tone (the frequency of which is given above each graph) was then increased beyond its threshold value by the num-

FIG. 8.



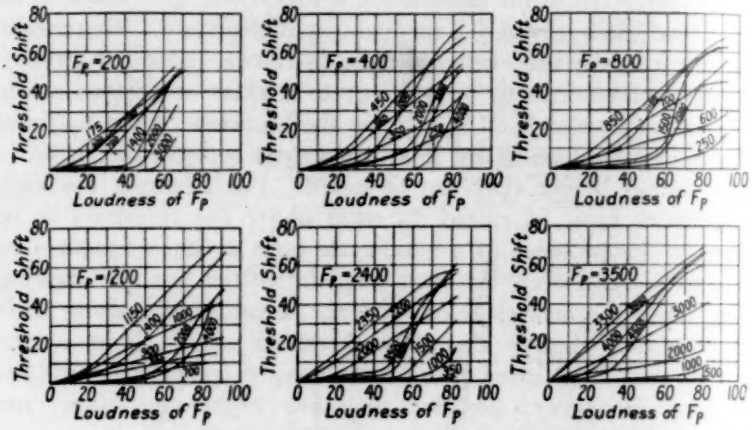
ber of units indicated just above the curve. The masked tone was then increased in intensity until its presence was just perceived. The amount of this latter increase, measured on the loudness scale is called the *threshold shift* and is plotted as ordinate in Figs. 8, 9 and 10. The frequencies of the masked tones are given by the abscissæ.

For example, in the fourth chart, the masking effects of the tone having a frequency of 1200 cycles are shown. It is seen that the greatest masking effect is near 1200 cycles, which is the frequency of the masking tone. A tone of 1250 cycles must be raised to 46 units above the threshold to be perceived in the presence of a 1200-cycle tone which is 60 units above its threshold, or it must be raised to within 14 units of the masking tone before it is perceived. This corresponds to an intensity ratio between the tones of only 25. A tone of 3000 cycles, however, can be perceived in the presence of a 1200-cycle tone which is 60 units loud when it is only 8 units above its threshold. This means that the intensity ratio between these two tones, under such circumstances, corresponds to 52 units or to a ratio of approximately 160,000 in intensity. However, as the loudness of the masking tone is increased, all of the high tones must be increased to fairly large values before they can be heard. For example, the high frequencies must be raised 75 units above the threshold to be heard in the presence of a 1200-cycle tone having a loudness of 100 units. But even for such large intensities for the masking tone, those frequencies below 300 are perceived by raising their loudness only slightly above the threshold value. It should be noticed that in all cases, those tones having frequencies near the masking frequency, whether they are higher or lower, are easily masked.

It is thus seen that Mayer's conclusion that a low pitch sound completely obliterates higher pitched tones of considerable intensity and that higher pitched frequencies will never obliterate lower pitched tones is true only under certain circumstances. A low tone will not obliterate to any degree a high tone far removed in frequency, except when the former is raised to very high intensities. Also a tone of higher frequency can easily obliterate a tone of lower frequency if the frequencies of the two tones are near together. When the two tones are very close together in pitch the presence of the masked tone is perceived by the beats it produces. This accounts for the sharp drop in the curves at these frequencies. A similar thing happens for those regions corresponding to harmonics of the masking frequency. In the charts for the 200- and 400-cycle masking tones these drops are not shown inasmuch as they were small, but in an accurate picture they should be shown.

In Fig. 9, these results are shown plotted in a different way. The abscissæ represent the loudness of the primary tones whose frequency is indicated at the top of each of the charts. The amounts that the threshold is shifted are plotted as ordinates as in the previous figure. For example, in Chart 1, the results are shown for a masking tone of 200 cycles. The curve marked 3000 indicates the masking effect of a 200-cycle upon a 3000-cycle

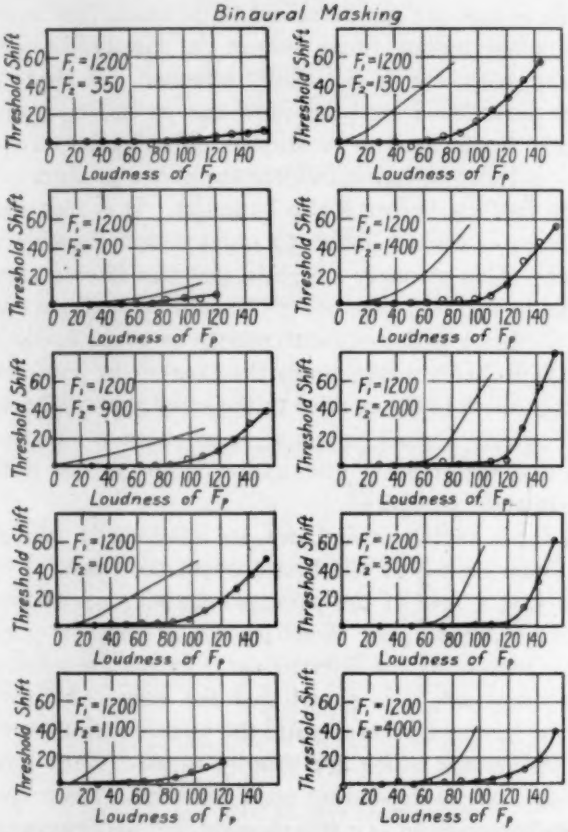
FIG. 9.
Monaural Masking



tone. It is seen that the loudness of the low pitched tone can be raised to 55 units before it has any interfering effect upon the high pitched tone. For louder values than this it has a very marked effect. It will be noticed that in nearly all of the charts the curves for different frequencies intersect. This leads to some rather interesting conclusions regarding the perception of a complex tone. For example, consider the curves for a masking tone having a frequency of 400 cycles. Assume we have a complex tone having three frequencies of 400, 300 and 200 cycles with relative loudness values of 50, 10 and 10, respectively. The ear will hear only the 400-cycle tone and the 2000-cycle tone as is evident from the curves. It would be necessary to raise the 300-cycle tone above 16 units for it to be heard in the presence of 400 cycles of loudness 50. However, if the sound is magnified without distortion 30 loudness units, so that these three frequencies have loudness values of 80, 40 and 40, respectively, then the

400-cycle tone and 300-cycle tone only will be heard. Under such conditions, the 300-cycle tone could be attenuated approximately 15 units before it would disappear. This means that the sensation produced by a complex sound is different in character as

FIG. 10.



well as in intensity when the sound is increased or decreased in intensity without distortion. In general, as the tone becomes more intense the low tones become more prominent because the high tones are masked. It is a common experience of one working with complex sounds to have the low frequencies always gain in prominence as the sound is amplified.

The question naturally arises, "Does the same interfering effect exist when the two tones are introduced into opposite ears

instead of both being introduced into the same ear?" The answer is "No." Curves showing the results in such tests are shown in Fig. 10. For comparison the results for the case when the tones are both in the same ear are given by the light lines. Take the case of 1200 and 1300 cycles. It is rather remarkable that a tone in one ear can be raised to 60 units, that is, increased in intensity one million times, before the threshold value for the tone in the other ear is noticeably affected. If the 1300-cycle tone were introduced into the same ear as the 1200-cycle tone, its loudness would need to be shifted 40 units, corresponding to a 10,000-fold magnification in intensity above its threshold intensity in the free ear before it can be heard. It is seen that if one set of curves is shifted about 50 units it will coincide with the second set. This strongly suggests that the interference in this case is due to the loud tone being transmitted by bone conduction through the head with sufficient energy to cause masking. The vibration is probably picked up by the base of the incus and transmitted from there to the cochlea in the usual way. There is other evidence* which I shall not have space here to discuss, which indicates that the effective attenuation from one ear to the other is approximately 50 units.

With these facts in mind, we are now ready to discuss the theory of hearing which will best account for them. I will refer briefly to just a few of the principal theories of hearing which have been proposed. The sketch shown in Fig. 11 gives a diagrammatic picture of the internal ear. In the Helmholtz theory, as first formulated, it is stated that the organ of Corti located between the basilar membrane and the tectorial membrane act like a set of resonators which are sharply tuned. Each tone stimulates a single organ depending upon its pitch. Later this theory was somewhat modified as it was thought that the resonant property might reside in one of the membranes in the cochlea.

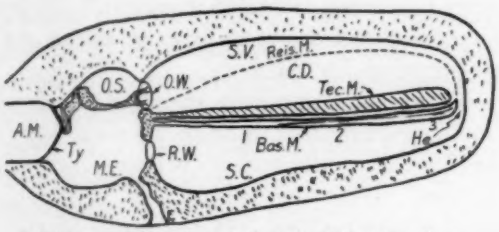
In the "telephone" theory, as expounded by Voltalini, Rutherford, Waller and others, it is assumed that the basilar membrane vibrates as a whole like the diaphragm of a telephone receiver,

* See paper by Wegel and Lane soon to be published in the *Physical Review* entitled "The Auditory Masking of One Pure Tone by Another and Its Relation to the Dynamics of the Inner Ear."

and consequently responds to all frequencies with varying degrees of amplitude. The discrimination of pitch takes place in the brain.

Meyers in his theory states that various lengths of the basilar membrane are set in motion depending upon the intensity of the stimulating tone. As in the previous theory, the pitch discrimination is accomplished in some way in the brain.

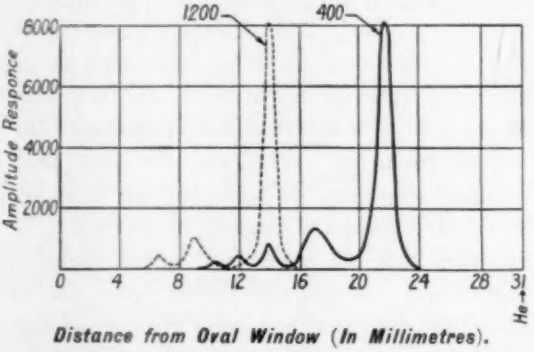
FIG. 11.



Diagrammatic representation of auditory function.

A. M.	Auditory meatus	O. W.	Oval window
Bas. M.	Bas. mem. including organ of Corti	Reis. M.	Reissner's mem.
C. D.	Cochlear duct	R. W.	Rd. window
E.	Eustachian tube	S. C.	Scala cochlea
He.	Helicotrema	S. V.	Scala vestibuli
M. E.	Middle ear	Tec. M.	Tectorial membrane
O. S.	Ossicles (malleus, incus, stapes)	Ty.	Tympanic membrane

Response of Basilar Membrane for Loudness of 80.



Distance from Oval Window (In Millimetres).

In the " non-resonant " theory of Emile ter Kuile it is assumed that the sound disturbance penetrates different distances into the cochlea depending upon the frequency of the stimulating tone. The further along the membrane the disturbance reaches, the lower will be the pitch sensation. A low pitch tone then stimulates all of the nerve fibres that would be stimulated by tones of higher pitch plus some additional nerve fibres.

The theory of maximum amplitudes was first put into definite form by Gray in 1899.[69] It assumes that the position of maximum amplitude of the basilar membrane varies with the pitch of the stimulating tone. Although a considerable portion of the membrane vibrates when stimulated by a pure tone, the ear judges the pitch by the position of maximum response of the basilar membrane. Roaf has shown that some action of this sort must take place due to the dynamical constants involved.[61] It is an amplification of this theory that I desire to propose as the one which most satisfactorily accounts for the facts.

When a sound wave impinges upon an ear-drum, its vibrational motion is communicated through the middle ear (Fig. 11) by means of the chain of small ossicles (malleus, incus and stapes) to the oval window. Here the vibration is communicated to the fluid contained in the cochlea. If the pitch of the tone is low, say below 20 vibrations, the fluid is moved bodily back and forth around the basilar membrane through the helicotrema, the motion of the membrane at the round window and the oval window being just opposite in phase, the former moving inward while the latter moves outward. For very high frequencies, the mass reactions of the ossicles and the fluid are so great that very little energy can be transmitted to the cochlea. For example, when the elastic forces are negligible it requires a force 10,000 times as large to produce the same amplitude of vibration at 10,000 cycles as that required at 100 cycles. For intermediate frequencies the mass reactions, the elastic restoring forces and the frictional resistances which are brought into play are such that the wave is transmitted through the basilar membrane causing the nerves to be excited.

It is thus seen that the upper and lower limits of audibility are easily explained. When the forces upon the drum of the ear or walls of the ear canal are large enough to excite the sensation of feeling and the pitch of the tone is either too low or too high to cause any perceptible vibration of the basilar membrane, we are beyond the lower or upper limit of audibility respectively. At frequencies between these limits, the vibrational energy is first communicated to the fluid in the scala vestibuli and then transmitted through the two membranes into the fluid of the scala cochlea. As the basilar membrane transmits the sound wave it takes up a vibration amplitude which stimulates the nerve

fibres located in it. The entire membrane vibrates for every incident tone, but for each frequency there is a corresponding spot on the membrane where the amplitude of the vibration is greater than anywhere else. Our postulate is that only those nerves are stimulated which are at the particular parts of the membrane vibrating with more than a certain critical amplitude; and that we judge the pitch from the part of the membrane where the nerves are stimulated. According to this conception, the variation with frequency of the minimum audible intensity is due principally to the variation with frequency of the transmission efficiency of the mechanical system between the auditory meatus and the basilar membrane. Pure tones of equal loudness correspond either to equal amplitudes or to equal velocities of vibration of the basilar membrane or to some function of the two. Whatever is assumed, the dependence of the minimum audible intensity upon frequency for the ear can be explained entirely by the vibrational characteristics of the ear mechanism. For the sake of clearness it will be assumed that equal amplitudes of vibration of the basilar membrane correspond to equal sensations. For loud pure tones, there are several regions of maximum amplitude on the membrane, corresponding to the tone and to the harmonic introduced by the non-linear response of the middle ear, the latter maxima increasing very rapidly as the stimulation increases.

It is a strange thing that the phenomenon of the masking of tones which, as stated in the beginning, has been considered by some to be so fatal to any resonator theory, is the very thing that has furnished experimental data which makes it possible to calculate the vibration characteristics of the inner ear. Such a calculation must be based upon assumptions which will be uncertain, but will seem reasonable. It is not my purpose to discuss those here, but I shall give only the final result of such a calculation made by Mr. Wegel and Mr. Lane of our laboratories. At the bottom of Fig. 11, the two curves show the amplitude of vibration of different portions of the basilar membrane for the two frequencies 400 and 1200 cycles. For purposes here these curves may be considered to be simply illustrative. This membrane has a length of 31 mm. and a width of .2 mm. at the base and .36 mm. at the helicotrema end. The x-axis in this figure gives the dis-

tance in millimetres from the oval window and the y-axis gives the amplitudes of vibration in terms of the amplitude corresponding to the threshold of audibilty. The loudness of the stimulating tones in both cases is 80 units. It will be seen that the maximum response for the high frequencies is near the base of the cochlea, while that for the low frequencies is near the helicotrema. It will be noticed that the amplitude of the membrane has several maxima corresponding to the subjective harmonics.

With this picture in mind, it is clear why the perception of one tone is interfered with by the presence of a second tone when their frequencies are close together, since the nerves necessary to perceive the first tone are already stimulated by the second tone. Also when their frequencies are widely separated, entirely different sets of nerves carry the impulses to the brain, and consequently there is no interference between the tones except that which occurs in the brain. Although this brain interference may not be entirely negligible, especially for very loud sounds, it is certainly very much smaller than that existing in the ear for tones close together in pitch.

It is also seen that the reason why the low tones mask the high tones very much more easily than the reverse is due to the harmonics introduced by the transmission mechanism of the ear. Inasmuch as these harmonics are due to the second order modulations, they are proportional to the square of the amplitude and, therefore, become much more prominent for the large amplitudes. When two tones are introduced, summation and difference tones as well as the harmonics will necessarily be present (see Appendix B). With the proper apparatus for generating continuously sounding tones, these subjective tones are easily heard. Their frequency can be quite accurately located by introducing from an external source a frequency which can be varied until it produces beats with the subjective tone.

Messrs. Wegel and Lane who are working in this field have observed modulation frequencies created in the ear as high as the fourth order. They will soon publish* an account of this work on the vibrational characteristics of the basilar membrane. It is seen that the quality as well as the intensity of the sensation produced by a pure tone should change as the intensity of stimulus

* Wegel and Lane, see paper already cited.

is increased due to the increasing prominence of the harmonics. This is in accordance with one's experience while listening to pure tones of varying intensity. The non-linear character of the hearing mechanism is also sufficient to account for the falling off in the ability of one to interpret speech when it becomes louder than about 75 units. The introduction of the summation and difference tones and the harmonics makes the interpretation by the brain more difficult. Its action in this respect is very similar to the carbon transmitter used in commercial telephone work or to an overloaded vacuum tube. This characteristic of the ear also explains why we should expect departures from non-linearity when making loudness balances for complex tones. It also suggests that a similar thing might be expected when comparing the loudness of pure tones if the balances are made at very high intensities. No such balances have yet been made.

What happens to the ear when one becomes deaf? This question, of course, is one for the medical profession to answer, but let us take one or two simple cases and see if they fit into this theory. First assume that the nerve endings are diseased for a short distance away from the base of the cochlea so that they send no impulses to the brain. Under certain assumptions the kind of an audiogram one should obtain can be calculated from the vibrational characteristics determined as mentioned above. Such a calculation shows that an audiogram similar to that shown in Fig. 4, which has a rapid falling off in sensitiveness, can be accounted for, both quantitatively as well as qualitatively. On a pure resonant theory corresponding to that first proposed by Helmholtz, a tone island would exist corresponding to the affected region for such a case. Although we have tested a large number of cases, no such islands have ever been found. When the intensity of the tone is raised sufficiently to bring the amplitude of the area containing the healthy nerve cells which are adjacent to the diseased portion to a value above that corresponding to the threshold, the tone will then be perceived.

Again assume that due to some pathological condition, the tissue around the oval window where the stapes join the cochlea has become hardened. Its elasticity will then be greatly increased so that vibrational energy at low frequencies will be greatly dis-

criminated against. For such a case, an audiogram similar to that shown in Fig. 7-B would be obtained.

A number of things can cause a general lowering of the ear sensitivity, such as wax in the ear canal, affections of the ear-drum, fixation of any of the ossicles, thickening of the basilar membrane, affections of the nerve endings or loss in nervous energy being supplied to the membrane, etc. However, one would expect that each type of trouble would discriminate, at least to some extent, against certain frequency regions so as to produce some characteristic in the audiogram. Ear specialists are beginning to realize the possibility of obtaining considerable aid in the diagnosis of abnormal hearing from such accurate audiograms.

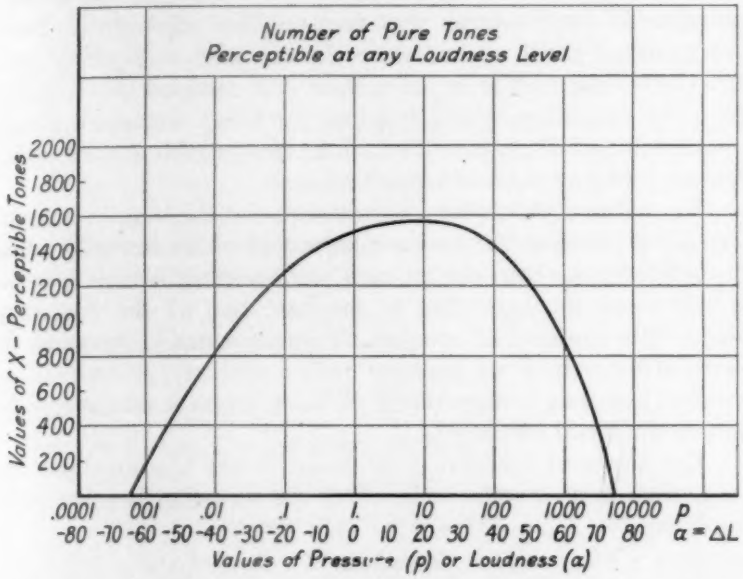
There are a large number of facts obtained from medical research which necessarily have a bearing upon the theory of hearing, but as far as I know none of them is contrary to the theory of hearing given above. It was seen that there are approximately 300,000 tone units in the auditory-sensation area. According to the anatomists, there are only 4000 nerve cells in the basilar membrane with four or five fibre hairs for each cell. Assuming that each hair fibre acts as a unit there are still insufficient units for each perceivable tone and according to the theory given above, a large number of these units must act at one time. Consequently the ear must be able to interpret differences in the intensity of excitation of each nerve cell as well as determine the position of each nerve cell excited.

Most modern neurologists believe in the " none or all " excitation theory of nerve impulses.[59-60] They also claim that nerve impulses can never be much more rapid than about 50 per second and cannot therefore follow frequencies as high as those found in sound waves. The second statement only emphasizes the necessity of assuming that the intensity position as well as place position is necessary to account for the differentiation of pure tones. The first statement is not necessarily in conflict with such an idea since anatomists are not agreed upon the number of nerve fibres radiating from each nerve cell. Since each nerve fibre can serve to give a unit nerve impulse, the intensity of stimulation sent from a single nerve cell can increase with stimulation depending upon the number of nerve fibres brought into action. The intensity of the sensation produced is then directly related to the total number

of nerve fibres giving off impulses. It seems to me that the spacial and intensity configurations which are possible, according to this theory, are sufficient for an educated brain to interpret all the complex sounds which are common to our experience.

In conclusion then, it is seen that the pitch of pure tones is determined by the position of maximum response of the basilar

FIG. 12.



membrane, the high tones stimulating regions near the base and the low tones regions near the apex of the cochlea.

A person can sense two mixed tones as being distinctly two tones while he cannot sense two mixed colors, since in the ear mechanism there is a spacial frequency selectivity while in the eye mechanism there is no such selectivity.

The limiting frequencies which can be perceived are due entirely to the dynamical constants of the inner ear as is also the dependence of minimum audible intensity on frequency.

The so-called subjective harmonics, summation and difference tones are probably due to the non-linear transmission characteristics of the middle and inner ear.

These subjective harmonics account for the greater masking effect of low tones on high tones than high tones on low tones.

Due to this non-linear characteristic, the quality as well as the intensity of the sensation produced, especially by complex tones, change as the intensity of the stimulus increases.

The facts obtained from audiograms of abnormal hearing are consistent with the theory of hearing which has been outlined.

Although this theory of hearing involves the principle of resonance, it is very different from the Helmholtz theory as usually understood. In the latter it is assumed that there are four or five thousand small resonators in the ear, each responding only to a single tone; while in the former it is assumed that a single vibrating membrane which vibrates for every impressed sound is sufficient to differentiate the various recognizable sounds by its various configurations of vibration form.

A loudness scale has been chosen such that the loudness change is equal to ten times the common logarithm of the intensity ratio. A pitch scale has been chosen such that the pitch change is equal to 100 times the logarithm to the base two of the frequency ratio. The loudness of complex or simple tones is measured in terms of the number of loudness units a tone of 700 cycles must be raised above its average threshold value before it sounds equally loud to the sound measured.

The degree of deafness is measured by the fractional part of the normal area of audition in which the sensation is either lacking or false.

APPENDIX A.

The calculations of the number of pure tones perceivable as being different in pitch at a given intensity or being different in loudness at a given pitch involves a line integral. The calculation of the number of pure tones perceivable as being different either in loudness or pitch involves a surface integral.

Let the coördinates used in Fig. 1 corresponding to $\triangle L$ and $\triangle P$ be designated α and β, respectively. Then the relations shown in Figs. 2 and 3 can be expressed by the equations

$$\frac{\triangle E}{E} = f(\alpha - \alpha_0) \text{ and} \tag{1}$$

$$\frac{\triangle N}{N} = \varphi(\beta) \tag{2}$$

where α_0 is the value of α along the normal minimum audibility curve shown in Fig. 1. Knudsen data indicated that the curve

shown in Fig. 3 held only for values of $\alpha - \alpha_0$ corresponding to the flat part of the curve in Fig. 2. For lower intensities the pitch discrimination fell off in about the same way as that shown for the intensity discrimination. To represent this mathematically, $\varphi(\beta)$ can be multiplied by a factor which is unity for the loud tones and which increases similarly to $f(\alpha - \alpha_0)$ for the weaker tones. Such a factor is $10 f(\alpha - \alpha_0)$ since $f(\alpha - \alpha_0)$ is approximately $\frac{1}{10}$ for the louder tones. So the corrected formula for $\frac{\triangle N}{N}$ is

$$\frac{\triangle N}{N} = 10\,\varphi(\beta) \cdot f(\alpha - \alpha_0) \tag{3}$$

Let dx be the number of perceivable tones of constant intensity corresponding to α in the pitch region between β and $\beta + d\beta$ and let dy be the number of perceivable tones of constant pitch corresponding to β in the region between α and $\alpha + d\alpha$. Then

$$dx = \frac{dN}{\triangle N} \tag{4}$$

$$dy = \frac{dE}{\triangle E} \tag{5}$$

But the values of α and β are given by

$$\beta = 100 \log_2 N \tag{6}$$

$$\alpha = 10(\log_{10} E - \log_{10} E_1) \tag{7}$$

where E_1 is the value of intensity corresponding to a pressure amplitude of 1 dyne.

Substituting values of dN and dE in terms of α and β we have

$$dx = \frac{1}{100} \frac{N}{\triangle N} \log_e 2\, d\beta = \frac{\log_e 2}{1000} \frac{d\beta}{\varphi(\beta) \cdot f(\alpha - \alpha_0)} \tag{4'}$$

$$dy = \frac{1}{10} \frac{E}{\triangle E} \log_e 10\, d\alpha = \frac{\log_e 10}{10} \frac{d\alpha}{f(\alpha - \alpha_0)} \tag{5'}$$

The number of tones of constant intensity which are perceivable as different in pitch is then

$$x = \frac{\log_e 2}{1000} \int_{\beta_1}^{\beta_2} \frac{d\beta}{\varphi(\beta) \cdot f(\alpha - \alpha_0)}$$

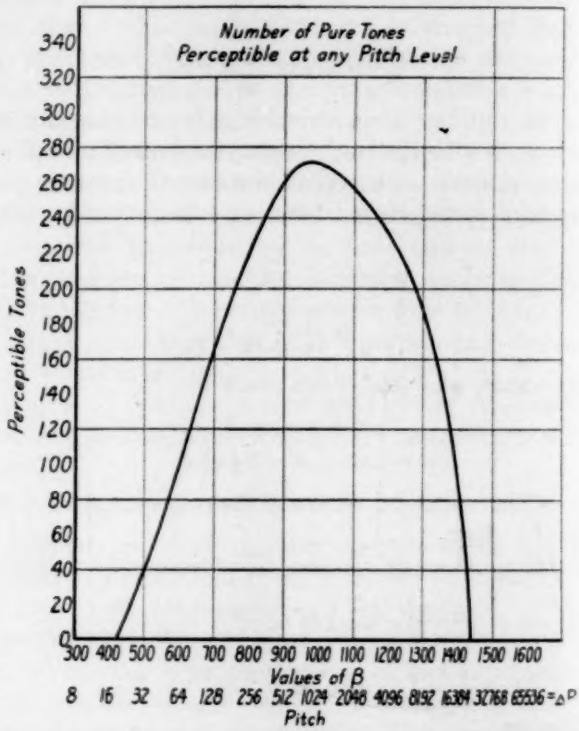
where β_1 and β_2 are the points where the particular intensity line cuts the boundary lines of the auditory-sensation area. For example, the limits for the line corresponding to 1-dyne pressure

amplitude are 500 and 1420. Similarly the number of tones of constant pitch which are perceivable as being different in loudness is given by

$$y = \frac{\log_2 10}{10} \int_{\alpha_1}^{\alpha_2} \frac{d\alpha}{f(\alpha - \alpha_0)}$$

where α_1 and α_2 are determined by the intersection of the particular pitch line with the boundary lines of the auditory-sensation area.

FIG. 13.



The values of these integrals were computed graphically. Figs. 12 and 13 show the results of these calculations. It is seen that the maximum number of tones perceivable as different in loudness is in the frequency range 700 to 1500 which is also the important speech range. The number in this range is approximately 270.

In the pressure range from 1 to 100 there are approximately 1500 tones which can be perceived as being different in pitch.

FIG. 14.

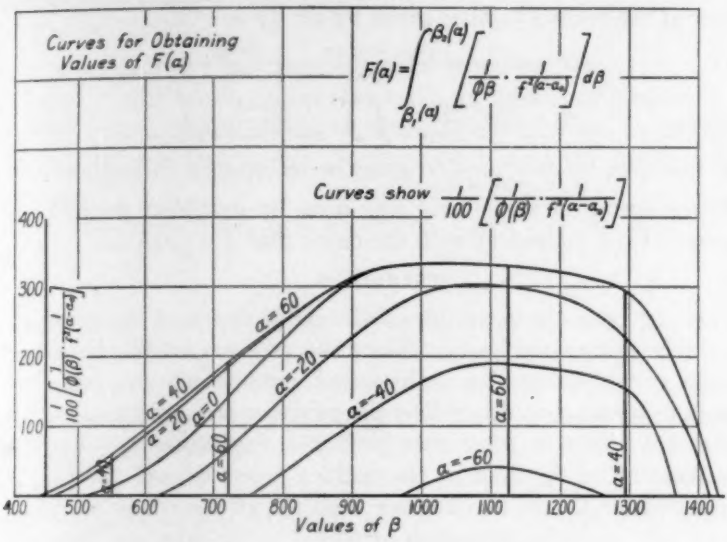
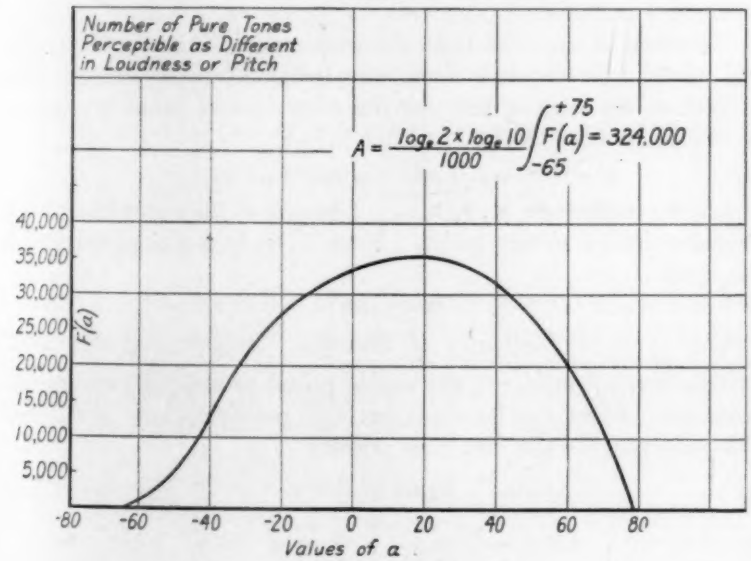

Curves for Obtaining Values of F(α)
F(α)=∫ [1/φβ · 1/f²(α−α₀)] dβ
Curves show 1/100 [1/φ(β) · 1/f²(α−α₀)]
400
300
200
100
α=60
α=40
α=20
α=0
α=-20
α=-40
α=-60
400 500 600 700 800 900 1000 1100 1200 1300 1400
Values of β

FIG. 15.


Number of Pure Tones Perceptible as Different in Loudness or Pitch
A = log_e 2 × log_e 10 / 1000 ∫ from −65 to +75 F(α) = 324.000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
F(α)
-80 -60 -40 -20 0 20 40 60 80
Values of α

The number of tones ΔT in a small area $d\beta\, d\alpha$ situated with one corner at the point (α, β) is given by $dx\, dy$ or

$$\Delta T = dx\, dy = \frac{\log_e 2 \log_e 10}{10{,}000} \frac{d\alpha\, d\beta}{\varphi(\beta) f^2(\alpha - \alpha_0)}$$

$$T = \frac{\log_e 2 \log_e 10}{10{,}000} \int\int \frac{d\alpha\, d\beta}{\varphi(\beta) f^2(\alpha - \alpha_0)}$$

The function $\frac{1}{\varphi(\beta) \cdot f^2(\alpha - \alpha_0)}$ must be integrated throughout the auditory-sensation area. This was done by graphical methods as shown in Figs. 14 and 15 with the result that $T = 324{,}000$.

APPENDIX B.

Let the pressure variation of the air in front of the drum of the ear be designated by δp. Since the pressure of the air in the middle ear balances the undisturbed outside air pressure this change in pressure multiplied by the effective area of the ear-drum is the only effective force that produces displacements. Let the displacement of the fluid of the cochlea near the oval window be designated by X. If Hookes law held for all the elastic members taking part in the transmission of sound to the inner ear then

$$X = k\delta p \tag{1}$$

where k is a constant.

It would be expected from the anatomy of the ear that Hookes law would start to break down even for small displacements. So in general the relation between the force δp and the displacement X can be represented by

$$X = f(\delta p) = a_0 + a_1\delta p + a_2(\delta p)^2 + a_3(\delta p)^3 + \cdots \tag{2}$$

where the coefficients $\alpha_0, \alpha_1, \alpha_2 \ldots$ belong to the expansion of the function into a power series. Now if δp is a sinusoidal variation then

$$\delta p = p_0 \cos \omega t \tag{3}$$

where $\frac{\omega}{2\pi}$ is the frequency of vibration. Substituting this value in (2), terms containing the cosine raised to integral powers are obtained. These can be expanded into multiple angle functions. For example, for the first four powers

$$\cos^2 \omega t = \frac{1}{2} \cos 2\omega t + \frac{1}{2} \tag{4}$$

$$\cos^3 \omega t = \frac{1}{4} \cos 3\omega t + \frac{3}{4} \cos \omega t \tag{5}$$

$$\cos^4 \omega t = \frac{1}{8} \cos 4\omega t + \frac{1}{2} \cos 2\omega t + \frac{3}{8} \tag{6}$$

It is evident then that the displacement X will be represented by a formula

$$X = b_0 + b_1 \cos \omega t + b_2 \cos 2\omega t + b_3 \cos 3\omega t + \cdots$$

In other words when a periodic force of only one frequency is impressed upon the ear-drum this same frequency and in addition all its harmonic frequencies are impressed upon the fluid of the inner ear.

If two pure tones are impressed upon the ear then δp is given by

$$\delta p = p_1 \cos \omega_1 t + p_2 \cos \omega_2 t$$

If this value is substituted in equation (2), terms of the form $\cos^n \omega_1 t$ and $\cos^m \omega_2 t$ and $\cos^n \omega_1 t \cos^m \omega_2 t$ are obtained. The first two forms give rise to all the harmonics and the third form gives rise to the summation and difference tones. For example, the first four terms are

$$a_0 = a_0$$

$$a_1 \delta p = a_1 (p_1 \cos \omega_1 t + p_2 \cos \omega_2 t)$$

$$a_2 (\delta p)^2 = a_2 \left[\frac{1}{2} p_1^2 \cos 2\omega_1 t + \frac{1}{2} p_2^2 \cos 2\omega_2 t + p_1 p_2 \right.$$
$$\left. \{\cos(\omega_1 - \omega_2)t + \cos(\omega_1 + \omega_2)t\} + \frac{1}{2} (p_1^2 + p_2^2) \right].$$

$$a_3 (\delta p)^3 = a_3 \left[\left(\frac{3}{4} p_1^2 + \frac{3}{2} p_1 p_2^2 \right) \cos \omega_1 t + \frac{1}{4} p_1^3 \cos 3\omega_1 t + \right.$$
$$\left(\frac{3}{4} p_2^3 + \frac{3}{2} p_1^2 p_2 \right) \cos \omega_2 t + \frac{1}{4} p_2^3 \cos 3\omega_2 t + \frac{3}{4} p_1^2 p_2 \cos(\omega_2 t + 2\omega_1 t)$$
$$+ \frac{3}{4} p_1^2 p_2 \cos(\omega_2 t - 2\omega_1 t) + \frac{3}{4} p_1 p_2^2 \cos(\omega_1 t + 2\omega_2 t)$$
$$\left. + \frac{3}{4} p_1 p_2^2 \cos(\omega_1 t - 2\omega_2 t) \right]$$

Therefore unless there is a linear relation between a force acting on the ear-drum and the displacement at the oval window, that is unless all the coefficients in equation (2) are zero except a_1, all the harmonics and the summation and difference tones will be impressed upon the fluid in the cochlea of the inner ear.

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New Method for the Disinfection of Hides and Skins for Anthrax.—Anthrax is an occupational disease of the tanning industry, the spores being carried by the hides and skins. The present methods for the disinfection of hides and skins for anthrax are not entirely satisfactory. HENRY FIELD SMYTH and EDWIN FREDERIC PIKE, of the University of Pennsylvania (*Amer. Jour. Hygiene*, 1923, iii, 224-237), have studied the disinfectant action of the following reagents upon anthrax spores: Chlorine, bromine, iodine, hydrochloric acid, carbonyl chloride (phosgene), carbon tetrachloride, trichlorethylene, sulphur dioxide, and ammonia. Experiments were also made on hides. The results obtained by Smyth and Pike demonstrate the absolute efficacy of iodine as a disinfectant for anthrax, and the possibility of the use of iodine for this purpose in the tanning industry without the slightest injury to the hides. The iodine may be applied as a vapor, as an aqueous solution, or in solution in an easily volatile solvent such as carbon tetrachloride or a mixture of that compound with gasoline. J. S. H.

THE COEFFICIENT OF RECOMBINATION OF THE NATURAL IONS IN AIR, AND ALLIED PHENOMENA ASSOCIATED WITH WEAK ATMOSPHERIC IONIZATION.*

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I.

INTRODUCTION.

Earlier Methods and Results.—The equations governing the rate of increase of ions in a gas under the influence of a source of ionization producing q ions per c.c. per second, a coefficient of recombination α and a coefficient of diffusion D are

$$\frac{\partial n_+}{\partial t} = D\frac{\partial^2 n_+}{\partial x^2} + q - \alpha n_+ n_-$$

$$\frac{\partial n_-}{\partial t} = D\frac{\partial^2 n_-}{\partial x^2} + q - \alpha n_+ n_-$$

Several methods have been devised for determining α, the aim being usually to arrange the experiment so that diffusion is negligible and $n_+ = n_-$, in which case

$$\frac{dn}{dt} = q - \alpha n^2. \qquad (1)$$

If the source of ionization responsible for q is removed so that we obtain an equation which integrates to the form

$$\frac{1}{n} - \frac{1}{n_0} = \alpha t$$

we may obtain α by measuring the value of n at any instant t, and the value n_0 at the time $t = 0$ when the source is removed. In this form the equation was first used by J. J. Thomson and Rutherford,[1] the latter of whom[2] also investigated the truth of equation (1) as regards its form.

For the steady state, (1) gives

$$\alpha n^2 = q$$

* Communicated by Dr. W. F. G. Swann, Associate Editor of this JOURNAL.

[1] *Phil. Mag.*, **42**, p. 392 (1896).

[2] *Phil. Mag.*, **44**, p. 422 (1897), and **47**, p. 109 (1899).

which serves to determine α in terms of q and the number of ions per c.c. in this state. McClung [3] used this method.

The field intensity between two plates determines the time required to clear out the ions, and this time affects the loss by recombination. Langevin [4] and Thirkill [5] determined α from these losses under different field intensities.

Using the methods indicated above, and artificially produced ionization, various observers [6] have obtained the following results: α increases as the temperature is lowered, and over considerable ranges is proportional to the pressure. For dust-free gases under normal conditions, α varies between 0.9×10^{-6} and 2.1×10^{-6} cm.^{3}/sec. being for air about 1.6×10^{-6}. For atmospheric air (*i.e.*, some dust, moisture, etc., present) the value is about 4×10^{-6}.

Another important fact should be noted. Work done by Bragg and Kleeman,[7] Langevin, Moulin,[8] Wheelock,[9] Ogden [10] and Jaffé [11] has shown that when ions are produced in columns as in α-ray ionization, the recombination is more rapid than if the same number of ions were distributed uniformly throughout the ionization chamber. Plimpton [12] thus explained a high initial recombination obtained when using Röntgen rays, but in Part II it will be shown that the explanation in this case is open to question.

Recent Work.—In the work on recombination so far discussed the ions were produced by some strong local source which could be controlled. This will be called "artificial" ionization. No

[3] *Phil. Mag.*, 3, p. 283 (1902).

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attempts had been made to determine α, using the ever-present "natural" ionization. This was undertaken by the writer in 1916, using air which had been confined in the ionization chamber for some time. Other work made it necessary to leave the problem very soon after it was undertaken, but a preliminary unpublished value of about 1.6×10^{-6} was obtained.

Von Schweidler,[13] in 1918 and 1919, assumed there was in ordinary air a loss of ions by collisions with dust, smoke particles or other matter, and so wrote

$$\frac{dn}{dt} = q - \alpha n^2 - \gamma nN \qquad (2)$$

where N is the number per c.c. of these particles. This can be rewritten

$$\frac{dn}{dt} = q - \alpha n^2 - \beta n = q - n^2\left(\alpha + \frac{\beta}{n}\right) = q - \alpha' n^2$$

Results of experiments extending over a month gave values of α' varying between 9×10^{-6} and 115×10^{-6} with a mean value of 29×10^{-6} for outdoor air.

In view of these large values he wrote the steady state equation

$$q = \alpha n^2 + \beta n = n(\alpha n + \beta) = \beta' n.$$

The results of his earlier and later work may be summed up as follows:

TABLE I.

q	n	$\beta' \times 10^3$	Extremes, $\times 10^3$	Remarks.
26.11	1200	21.8	16 to 60	Innsbruck, well-ventilated room.
17.6	1080	16.6	12 to 42	Seeham, well-ventilated room.
13.6	712	19.1	16 to 35	Seeham, wooden house over the water.
29.5	740	42.2	18 to 98	Innsbruck, closed heated room.

In connection with the last observations he found that β' was independent of q even when the latter was increased by use of a mesothorium capsule to a value as high as 347 ions per c.c. per second.

Owing to the interruption of communications due to the war, the investigations here presented were undertaken without knowledge of Schweidler's work. There are so many phases of the

[13] *Akad. Wiss. Wien. Ber.*, **127** (2a), p. 953 (1918); *Akad. Wiss. Wien. Ber.*, **128** (2a), p. 947 (1919).

general subject, however, which did not come within the scope of his discussion or investigation that it was found possible to continue the present work without serious duplication of effort. His method of observation was found to be very similar to that employed in the preliminary work in 1916.

One of the outstanding features of Schweidler's results is the fact that the absorption particles in atmospheric air do not appear to be dust particles in the ordinary sense of the word, since β' remains fairly constant for wide variations in dust content. One of the main objects of the present investigation and of that made by the writer in 1916 was to determine whether, apart from the influence of dust, the mechanism of recombination for such weak ionization as occurs in the atmosphere is essentially different from that for the strong ionization usually employed in the laboratory. This question is of primary importance in determining how far it is justifiable to apply previous laboratory results to atmospheric phenomena.

METHODS OF MEASUREMENT.

The determination of α as first carried out involved the determination of q and n_∞ in the relation $q = \alpha n_\infty^2$, corresponding to the steady state.

The most obvious method of determining q is to measure the saturation current through the vessel, and make the necessary calculation in terms of the volume, and the electronic charge. Another method is founded upon the following principle. Without any assumption as to the law of recombination we can write for the non-steady state,

$$\frac{dn}{dt} = q - f(n)$$

where all that we need specify concerning $f(n)$ is that it is zero when n is zero. Thus the initial rate of growth of ions immediately after the vessel has been cleared of ions by a strong field, affords a direct measure of q.

The latter method has some advantages over the former, in that even though there is initial columnar recombination, the value of q measured in this way gives what we may regard as the true rate at which ions are supplied to the space, and it is therefore the appropriate value to use in a calculation of α from the formula $q = \alpha n_\infty^2$, which takes no account of initial recombination. The

value of q obtained from the saturation current would, on account of the high field used in measuring the current, include a part of the ionization which, in the absence of that field, would participate in the initial recombination. For the purpose of obtaining an estimate of the extent of this initial recombination, both methods of measuring q were employed.

There are two obvious ways of measuring n_∞. In the first, which was the one usually employed, the ions existing in the vessel in the steady state were swept out by the application of a high electric field. If Q is the quantity of electricity delivered to the insulated system under these conditions, after correction for the formation and recombination of ions during the process of sweeping them out, we may obtain n_∞ in terms of the electronic charge e and the volume V of the vessel by the relation $Q = n_\infty e V$.

The second method involves the measurement of the steady current obtained when between the electrodes is maintained a difference of potential which is so small that, except in the immediate vicinity of the electrodes, the value of n within the vessel is not appreciably disturbed from the value n_∞ by the passage of the current. Under these conditions, if Q_0 is the charge contained within any closed surface surrounding the central conductor, the current i coming to that surface is

$$i = -4\pi Q_0 ne(v_+ + v_-)$$

where v_+ and v_- are the mobilities of the positive and negative ions. The closed surface referred to must not be drawn so near the inner conductor that any part of it falls within the region in which n_+ and n_- vary. Thus Q_0 is not the actual charge on the central conductor. The relationship of these two quantities raises considerations concerning the very meaning of the capacity of such a system as is here considered. This question has an importance far beyond its bearing on the immediate problem of the coefficient of recombination of ions, and will be given careful consideration in Part II. As far as the present problem is concerned, it may be stated that the two methods indicated for determining n_∞ gave concordant results.

MATHEMATICAL FORMULAS AND CORRECTIONS.

It will be well at this point to consider the corrections which must be made to the Q from which n_∞ is obtained by the first method indicated above.

(*a*) For an approximate correction, the Q originally obtained should be diminished by a quantity equal to the saturation current for the time interval during which the observation lasts.

(*b*) After applying correction (*a*), we must increase Q to account for recombination during the interval of observation. If we assume a parallel plate condenser and that when the potential is applied all ions move toward the plates with the same velocity, then the region in which practically the whole recombination takes place is one which is symmetrical with respect to a plane equidistant from the plates, and which becomes zero after a time $T/2$, where T is the time required for an ion to travel the whole distance between the plates. The volume of this region at any time t after the potential is applied can be expressed by $V = V_0(1 - 2t/T)$ where V_0 is the volume of the vessel. The total number recombining in this region is

$$N = V_0 \alpha n_\infty^2 \int_0^{\frac{T}{2}} \left(1 - \frac{2}{T}t\right) dt$$

and since $\alpha n_\infty^2 = q$ the solution becomes

$$N = V_0 q\, T/4.$$

It is easy to apply a potential sufficiently high to make $T = 2$ seconds, and if we assume $q = 10$ ions per c.c. per second and $n = 1000$ ions per c.c., we obtain for the loss $N/V_0 n_\infty = 0.5$ per cent.

(*c*) At the end of the experiment there are still ions in the vessel. If we let d be the total distance between the plates and measure x from one of the plates, we have $n = q\ T\ x/d$, and the total number of ions of this class becomes $V_0 qT/2$. This correction to n_∞ is therefore about 1 per cent.

(*d*) The correction which presents the greatest difficulty is that for diffusion. During the progress of the work the solutions of three different differential equations involving diffusion were required. They were obtained as follows:

(1) The steady state equation

$$D\frac{d^2n}{dx^2} + q - \alpha n^2 = 0$$

may be integrated once and obtained in the form

$$\frac{dn}{dx} = \left(\frac{2\alpha}{3D}\right)^{\frac{1}{2}} \left(n^3 - \frac{3qn}{\alpha} - \frac{3a}{\alpha}\right)^{\frac{1}{2}}$$

where a is the constant of integration.

For a parallel plate condenser, if the plates are an infinite distance apart, at a great distance from either plate, n becomes n_∞, $q = \alpha n_\infty^2$, and $\frac{dn}{dx} = 0$. This gives $a = -2\alpha \; n_\infty^3/3$.

Substituting this value of a, putting αn_∞^2 for q and separating the variables, we obtain upon integrating

$$\left(\frac{2\alpha n_\infty}{3D}\right)^{\frac{1}{2}} x = \int_0^{\frac{n}{n_\infty}} \frac{d\left(\frac{n}{n_\infty}\right)}{\left[\left(\frac{n}{n_\infty}\right)^3 - 3\frac{n}{n_\infty} + 2\right]^{\frac{1}{2}}}$$

$$= \frac{1}{\sqrt{3}} \log \left[\frac{\sqrt{\frac{n}{n_\infty} + 2} - \sqrt{3}}{\sqrt{\frac{n}{n_\infty} + 2} + \sqrt{3}} \cdot \frac{\sqrt{2} + \sqrt{3}}{\sqrt{2} - \sqrt{3}}\right]$$

where x is the distance from the plate.

In Table II are given corresponding values of n/n_∞ and x (in row x_α), assuming that $D = 0.04$ cm.^{2}/sec. and $\alpha n_\infty = 8 \times 10^{-3}$.

Making the assumption that the first ionization chamber used could be treated as a parallel plate condenser with plates 12.6 cms. apart and containing the same volume as the ionization chamber, and making the further assumption that the total number of ions lost by diffusion would be no greater even if the plates were an infinite distance apart, the loss is found by graphical integration to be 29 per cent.

(2) Using the boundary conditions that $n/n_\infty = 0$ when $x = 0$, the solution of the steady state equation

$$D\frac{d^2n}{dx^2} + q - \beta n = 0$$

was obtained in the form

$$\frac{n}{n_\infty} = 1 - e^{-\sqrt{\frac{\beta}{D}}x}.$$

In Table II are included corresponding values of n/n_∞ and x (in row headed x_β) obtained from this equation. Again $D = 0.04$ and $\beta = 8 \times 10^{-3}$. This is the value of αn_∞ used previously and so the resulting values of x may be compared directly. Making the assumptions used in the previous case, the diffusion loss is found to be 36 per cent.

TABLE II.

$\frac{n}{n_\infty}$	0	0.2	0.4	0.6	0.8	0.9	0.95	0.97	0.99	0.995
x_α cms.	0	0.42	0.94	1.65	2.81	3.94	5.06	5.88	7.74	10.62
x_β cms.	0	0.51	1.12	2.03	3.56	5.08	6.74	7.76	10.5	13.0

(3) The non-steady state equation

$$\frac{\partial n}{\partial t} = D\frac{\partial^2 n}{\partial x^2} + q - \beta n$$

was solved as follows for the boundary conditions:

$n = 0$ when $t = 0$ for all values of x,

$n = 0$ when $x = 0$ for all values of t.

By making the substitution $n = N + q/\beta$, the equation reduces to the form treated in Byerly "Fourier Series and Spherical Harmonics" (page 90), and two particular solutions there given can be added to secure the boundary conditions desired in the present problem. Remembering that $q/\beta = n_\infty$ and replacing N by $n - q/\beta$ the solution may be written

$$\frac{n}{n_\infty} = 1 - \frac{2e^{-\beta t}}{\sqrt{\pi}}\int_0^{\frac{x}{2\sqrt{Dt}}} e^{-y^2}\,dy - \frac{2}{\sqrt{n}}\int_{\frac{x}{2\sqrt{Dt}}}^{\infty} e^{-y^2 - \frac{\beta x^2}{4Dy^2}}\,dy$$

This equation can be integrated with respect to x and obtained in the form

$$\frac{1}{n_\infty}\int_0^\eta n\,dx = \eta - \frac{2\eta}{\pi}e^{-\beta t}\int_0^{\frac{\eta}{2\sqrt{Dt}}} e^{-y^2}\,dy$$

$$- 2\sqrt{\frac{Dt}{\pi}}e^{-\beta t}\left(e^{-\frac{\eta^2}{4Dt}} - 1\right) - \sqrt{\frac{D}{\beta}}\sinh\eta\sqrt{\frac{\beta}{D}}$$

$$+ \sqrt{\frac{D}{\pi\beta}}\left[e^{\eta\sqrt{\frac{\beta}{D}}}\int_0^{\frac{\eta}{2\sqrt{Dt}} + \sqrt{\beta t}} e^{-y^2}\,dy\right.$$

$$\left. - e^{-\eta\sqrt{\frac{\beta}{D}}}\int_0^{\frac{\eta}{2\sqrt{Dt}} - \sqrt{\beta t}} e^{-y^2}\,dy - 2\int_0^{\sqrt{\beta t}} e^{-y^2}\,dy\right]$$

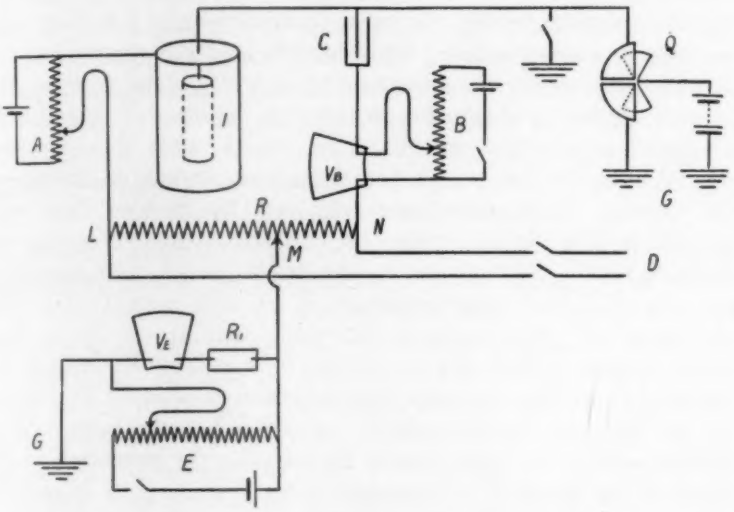
where η is half the distance between the plates. Having fixed D and β this can be immediately evaluated for any desired value of t. Dividing by η gives the average value of n/n_∞ at the time t.

In the absence of diffusion the solution of the non-steady state equation may be written

$$\frac{n_d}{n_\infty} = 1 - e^{-\beta t}$$

where n_d indicates the value of n in the absence of diffusion. From n/n_∞ and n_d/n_∞ a value of n/n_d may be obtained and any measured value of n corrected for diffusion. Using the values of

FIG. 1.



η, D and β, indicated previously, the results in Table III were obtained.

TABLE III.

Time in minutes.	∞	5	4	3.5	3	2.5	2	1.5	1	0.75	0.50	0.25
$\frac{n}{n_d}$	0.667	0.692	0.704	0.714	0.733	0.742	0.764	0.793	0.825	0.847	0.880	0.897

DESCRIPTION OF APPARATUS AND MANIPULATION.

During the progress of the investigation, ionization chambers of various sizes and forms were used, also the arrangement of apparatus and method of observation were varied to meet immediate requirements, but the arrangement used for the greater part of the work is indicated in Fig. 1.

The insulated electrode of the ionization chamber 1 was connected to one pair of quadrants of an electrometer Q whose

sensitivity varied in different experiments from 300 to 6000 divisions per volt. To prevent leakage from the outer wall of the ionization chamber to the central system, the latter was protected by an earthed guard ring. The potentiometer system A served to neutralize any contact difference of potential between the outer wall and the central cylinder. The potentiometer system B, in connection with the variable condenser C, served for calibration purposes. For most of the work, V_B was a standard millivoltmeter. The lead wires of the central system were carefully shielded by metal tubing. In order to avoid trouble resulting from the inductive action arising from variation of the potential of the batteries during the measurement of q, and for the further purpose of rendering it possible in the determination of n suddenly to apply a potential to the outer vessel with the electrometer system insulated and yet obtain no inductive deflection, the scheme of compensation devised by Swann was employed.[14] The leads from the battery were brought *via* D to the two ends of the resistance R, which was composed of coils of *IAIA* wire immersed in oil and wound to a total resistance of 30,000 ohms. If the potential of M is kept equal to zero or any definite value, it is possible to adjust the capacity C so that complete compensation is secured as regards the potential of the electrometer system when the battery D is thrown off or on. Moreover, by varying the potential of the point M by means of the potentiometer system E, it is possible to annul the change of potential of the electrometer system arising from the advent to that system of the charges which it is desired to measure, so that the magnitudes of these charges are obtained in terms of the readings of the millivoltmeter V_E, being in fact KV_E, where K is a constant. The sensitivity of V_E is varied at will by the series resistance R_1. In order to determine K the central system is first earthed, the switches in the circuits B and E are closed, and by trial the sliding contacts on the resistances are so set that upon releasing the electrometer from earth and then opening the two switches the electrometer does not deflect. The voltmeter reading V_E under these conditions indicates a quantity of electricity on the central system equal to $C \times V_B$. The inverse of this method of calibration may lead to error, for as soon as the point M (also L and N) is at a potential other than

[14] *Phys. Rev.*, 17, p. 240 (1921).

zero, this potential is applied to the outer wall of the ionization chamber and an ionic current results. Under the conditions above, $KV_E = CV_B$, which serves to determine K in terms of C and the measured potentials. The advantage of using the system E rather than B during the main measurements is that, during these measurements, the whole of the system B is at a potential appreciably different from zero, so that it is not desirable to handle it for the purpose of making adjustments.

All parts of the entire system except the batteries at D were carefully insulated from the ground, in fact the indicated "grounds" G were also carefully insulated from the actual ground, being merely connected at a common point. The purpose of this was to prevent leakage from the high potential batteries to any part of the system, as variable shunts across the high resistances would cause the voltages to fluctuate.

FIRST OBSERVATIONS AND RESULTS.

The first observations were made to verify the work done in 1916, no especial effort being made to purify the air. The ionization chamber consisted of coaxial sheet iron cylinders, the outer about 65 cms. in length and 43 cms. in diameter, the inner 40 cms. in length and 18 cms. in diameter. The effective volume was taken as 8.40×10^4 c.c. Tests indicated that 280 volts across the resistance R was sufficient to secure saturation; about half of this was across the ionization chamber. Test also showed that seven minutes were sufficient time for the ionization very nearly to reach its normal state; eight to ten minutes were usually allowed. Before taking observations the potentiometer A was so adjusted that with the high potential off there was no drift of the electrometer when released. The potential required to secure no drift did not remain exactly the same from day to day, but was always small. Next the system was balanced, *i.e.*, the capacity C and the resistances of R were so adjusted that removing the high potential produced no deflection of the electrometer.

In taking observations, the electrometer was released, the high potential applied and the electrometer held at its zero reading by increasing the potential V_E. After 30 seconds V_E was noted, and then at various other intervals of time afterward. The latter observations gave data for obtaining q, while the value of n_∞ was obtained from the first observation. The 30-second time interval allowed any initial electrometer oscillations to die out.

Besides the observations made with natural ionization, observations were made with radium bromide near the vessel. The results of these first observations may be seen in Table IV.

TABLE IV.

q		n_∞		$\alpha \times 10^6$	
+	−	+	−	+	−
14.35	14.2	2470	2580	2.4	2.1
14.6	14.3	2990	2820	1.6	1.8
17.15	17.35	3000	2720	1.9	2.3
17.2	17.7	3460	3130	1.4	1.8
20.4	20.8	3510	3230	1.7	2.0
38.3	38.5	5880	5470	1.1	1.3
63.6	64.8	6560	6130	1.5	1.7

The only corrections applied to n_∞ in the table are those discussed under (a) and (1) of (d). It is realized that the latter correction is only an approximation owing to the assumptions involved.

The values of α determined from measurements on negative ions appear in general to be greater than for the positive ions. This may be due to the greater loss of negative ions by diffusion.

RESULTS AFTER MODIFYING APPARATUS.

In order to minimize the uncertainty due to diffusion, measurements were made in a large cylindrical vessel whose effective volume was estimated to be 2.06×10^6 c.c. With this apparatus values of α as high as 100×10^{-6} were obtained, this resulting from $q = 23.6$ and $n = 486$, after adding a correction of 6 per cent. for loss by diffusion calculated in the same manner as before.

Investigations were immediately undertaken to determine the cause of these high values. To determine their reality, q and n_∞ were each measured by the two different methods indicated previously. The values of n were in agreement, those of q differed slightly, as is shown in Table VII, but the difference was not nearly sufficient to account for the large values of α obtained. A discussion of columnar ionization and its effect on the measured q will be given later, and the results obtained will there be considered.

The possibility was next considered of accounting for the large values of α on the basis of equation (2) as proposed by Schweidler. Various subsidiary experiments were made in this

connection, but a discussion of these matters will be postponed until after a method of determining α and β has been indicated and the results of measurements given.

TESTING OF n-t CURVES.

General Method.—The following procedure was adopted in determining values of q, α and β for the non-steady state equation

$$\frac{\partial n}{\partial t} = q + D\frac{\partial^2 n}{\partial x^2} - \alpha n^2 - \beta n.$$

Relying for justification upon results obtained, it is assumed that the αn^2 term is negligible in comparison with βn. The equation then reduces to one whose solution has been given, and by use of Table III the measured values of n obtained for various time intervals may be corrected for diffusion. A curve constructed from these values of n and t should then satisfy the equation

$$\frac{dn}{dt} = q - \beta n$$

whose solution, using the boundary condition $n = 0$ when $t = 0$, is

$$n = \frac{q}{\beta}(1 - e^{-\beta t}).$$

Various values of t were substituted in this equation and the values of q and β adjusted until the computed values of n agreed as well as possible with those taken from the corrected experimental curve.

Typical Set of Data.—A typical set of data will now be given and the results of the adjustment shown. The original ionization chamber was used in this work so that the purity of the air could be better controlled. The potential across the ionization chamber was about 400 volts and the time required for the observations was about three hours.

The figures recorded in Table V are the scale indications of the voltmeter V_E. The ions were allowed two hours to reach a steady state before commencing observations, then the last reading in the second column of the table was taken. A test for balance then showed that 2.2 should be added to the observed reading. The system was then balanced so that no further corrections of this kind were necessary. Next the data in the first line of the table were taken. This was followed by the data in column 2, then in columns 3, 4 and 5, and finally by the data in the second line of the table. The sixth column gives the average of the preceding

four. From this average is subtracted 10.72 to correct for ions formed during the experiment, and 0.6 is added for zero correction on the voltmeter. The corrected values appear in column seven, and these were converted into the values of n appearing in the next column by use of the following calibration data.

The charge resulting from a potential of 0.300 volt on the condenser C of capacity 68.5 cms., balanced the charge induced by the potential corresponding to a reading of 41.4 divisions on the voltmeter, giving the value 0.001631 e.s.u. of quantity per division, or 40.5 ions per c.c. per division, taking the volume as 8.40×10^4 c.c. and the ionic charge as 4.8×10^{-10} e.s.u. From the saturation current, q was found to be 14.5 ions per c.c. per second. The values of n_d were obtained from n by use of Table III.

TABLE V.

March 20, 1921.

q current in two minutes

0 to 42.1, 44.1, 42.7, 43.0, 42.0, 41.0, 42.6, 42.7, 43.5, 44.2.

Average q current in 30 seconds, 10.72.

Time for ions to form.	Voltmeter reading 30 seconds after throwing on potential.				Average.	Corrected for q and zero.	n	n_d
15 sec.	12.7	14.5	13.5	14.6	13.82	3.70	150	167
30	16.8	17.1	18.7	17.1	17.42	7.30	296	337
45	20.2	19.1	21.0	20.1	20.10	9.98	404	477
1 min.	21.9	22.4	23.9	23.2	22.85	12.73	516	626
1.5	28.2	28.0	27.6	28.3	28.02	17.90	725	914
2	29.8	30.2	31.0	30.9	30.48	20.36	825	1080
2.5	33.0	34.0	33.0	32.2	33.05	22.93	929	1250
3	35.3	37.1	36.4	35.5	36.08	25.96	1050	1434
3.5	38.8	38.4	36.7	36.4	37.58	27.46	1112	1560
4	39.5	39.0	39.0	38.8	39.08	28.96	1172	1666
2 hrs.	41.6	corrected for balance gives			43.8	33.7	1365	2070 $= n_\infty$

A curve $n_d - t$ was next plotted, and from this was taken the values of n_d and t given in the first two rows of Table VI. The third row gives the values computed for n, assuming $\alpha = 0$, $\beta = 4.6 \times 10^{-3}$, $q = 11.7$, using the equation $n = (1 - e^{-\beta t})q/\beta$. The agreement of the two values of n was considered good.

The value of β obtained is only about half that used in determining the diffusion corrections in Table III. Computed values of n_d, using this smaller value of β, are shown in the last line of

the table, and it is seen that even this change in β has relatively small effect upon the diffusion correction.

TABLE VI.

t (sec.)	18	37	58.5	81	106.5	139	174	220.5
n_d ($\beta = 8 \times 10^{-3}$)	200	400	600	800	1000	1200	1400	1600
n	203	396	599	790	983	1201	1400	1617
n_d ($\beta = 4.6 \times 10^{-3}$)	208	428	630	828	1205	1240	1436	1644

Results.—Twenty-four curves were obtained and tested in this way, assuming $\alpha = 0$, and the results are indicated in Table VII, in the columns headed "Tests of curves after correcting for diffusion." The column headed "R" indicates the percentages obtained by dividing the largest variation of n by the largest value of n used. The smallness of these variations is a measure of the justification of neglecting the αn^2 term in this work. Where no value of β accompanies that of q, the q was obtained from the initial slope of the curve.

The following remarks are supplementary to those appearing in Table VII. On January 28th, the vessel was filled with air, which was slowly filtered through cotton for a period of over two hours, and was obtained from a high-pressure cylinder which had been filled over a month previously so as to permit the decay of possible radium emanation content. On February 3rd, a small amount of radium emanation was introduced into the vessel without disturbing materially the conditions inside. On March 8th, the vessel was cleaned inside and a coating of glycerin applied, which, together with a small fan inside, aided in removing dust particles. On March 19th, the vessel was again cleaned, covered with glycerin, sealed as well as possible with cotton wool, and a dish of phosphorous pentoxide placed inside.

The data for the second curve on March 2nd was taken shortly after room air had been pumped into the vessel, and the original observations show that for any given value of t, the measured n was continually increasing, thus making it difficult to secure a good set of observations. For some of the curves the value of n corresponding to a given t depends upon only one or two observations, and the resulting inaccuracy in drawing the curve is thought to explain most of the two and three per cent. variations.

As a check on the values of β obtained from curve testing, β

was computed from the equation $\beta = q_c/n_\infty$, where q_c is the value of q obtained from curve testing and n_∞ is taken from the first

TABLE VII.

Date—1921.	n_∞ corrected for diffusion.	q from saturation current.	α $\left(=\frac{q}{n_\infty^2}\right)$	β $\left(=\frac{q_c}{n_\infty}\right)$	Test of curves after correcting for diffusion. q_c	β	R Per cent.	Remarks.
Jan. 19	2,040	12.6	3.0×10^{-6}	5.6×10^{-3}	11.4	5.0	1.2	Room air in Jan. 18.
20	1,470	11.7	5.4		10.2			
20	1,780	12.6	4.0	6.1	10.8	4.0	0.6	
20		12.45			8.4			
23	1,930	12.2	3.3					Natural ionization.
23	4,560	35.6	1.7	8.3	39.9	8.0	0.6	Radium bromide.
28	1,470	9.7	4.5					Filtered air.*
28	1,580	9.8	3.9	5.6	8.92	4.0	1.0	
30	1,480	10.5	4.8		8			
30	1,480	10.4	4.7	6.7	9.9	5.7	0.8	
30	4,070	30.3	1.8	7.9	32.2	7.0	1.1	Radium bromide.
Feb. 2	6,140	58.5	1.6	9.6	59.1	8.0	1.7	Radium bromide.
3	1,720	12.2	4.1					
3		12.2			9.5			
3	2,300	20.1	3.8					Emanation introduced.
3	2,270	21.0	4.1					
3		21.8			19.6	9.5	1.0	
3	2,530	23.0	3.6	8.0	20.3	7.0	0.8	
3	2,670	22.8	3.2		17			
3	4,390	39.6	2.1	9.7	38.5	7.0	2.5	Radium bromide.
3	2,720	23.6	3.2		14			
4	2,130	21.0	4.6					
4		20.7			15			
5	1,970	17.9	4.6		16			
5		44.7			38			Radium bromide.
12	1,590	13.2	5.2	9				
12	3,640	31.0	2.3	7.9	28.8	5.3	1.2	Radium bromide.
12	17,400	386	1.3	21	361	10	3.4	Radium bromide.
20	17,500	400	1.3	26	451	22	1.2	Radium bromide.
23	3,490	32.7	2.7	8.5	29.5	5.5	1.2	Radium bromide.
23		24.1			22.0	5.5	2.5	Radium bromide.
23		13.5			12.5	6.8	1.2	
27		13.0			11.2	6.5	1.9	
Mar. 2	1,640	13.3	4.9	6.5	10.9	5.2	1.5	Smoke in Feb. 27.
2		14.7			13.9	17	5.5	Room air pumped in.
12		11.6			10.5	5.3	2.2	Air in Mar. 8.
13	1,580	11.3	4.5	6.8	10.8	6.3	1.5	
20	1,930	14.5	3.9	6.1	11.7	4.6	1.1	Air in Mar. 19 with
25		18.8			16.1	6.0	1.1	phos. pentoxide and
29	1,880	17.8	5.0	7.7	14.4	6.6	1.1	glycerin.

*Introduced about four hours before.

column. These values of β should be given less weight, as each usually depends upon a single measurement of n_∞, while those

obtained from curve testing depend upon several measurements of n.

Tests were made to see if it were possible by a suitable choice of q and α to fit the experimental curves without the use of a β term. Using data taken soon after the introduction of radium emanation as being most favorable, but restricting q to values in the neighborhood of those obtained by experiment, the values of R obtained were of the order 30 per cent. Tests of other curves gave very similar results, thus showing the use of a β term to be necessary.

It is seen that the values of β vary over a comparatively small range, averaging 6.1×10^{-3} if the three large values obtained under unusual conditions are eliminated. In practically all cases the air had stood for some time. For fresh air where the dust has had little opportunity to settle, larger values would be expected as will be seen later, and as were actually found by Schweidler.

As a result of the curve testing, the conclusion seems justified that under the conditions existing during the observations the recombination due to the αn^2 term is negligible in comparison with that due to βn. This confirms Schweidler's conclusion that it is more appropriate to determine a coefficient of recombination depending upon the first power of the number of ions than one depending upon the square of this number. As pointed out previously, Schweidler decided that the absorption centres were not dust particles in the ordinary sense of the word. We now find that the β term predominates under a wide variety of conditions involving variation in the sources and degree of ionization, and different degrees of purity of the air, and that the n^2 term is still negligible even when special care is taken to entirely remove dust and moisture.

This shows that it is not justifiable to take the recombination coefficients obtained in the laboratory by methods using strong artificial ionization and apply them to natural ionization phenomena. The phenomena are quite distinct, possibly due to a non-uniform distribution of ions in the case of natural ionization. A recombination depending upon the first power of n may be accounted for on this basis as follows: Suppose the ionization and recombination to be confined to small isolated regions which are quite similar in nature. Then no matter what the law of recombination may be in each individual region, the total recombination

is proportional to the number of regions, that is to the number of ions, and any increase in the ionization which merely adds more regions of a similar nature will leave the proportionality factor unchanged. As soon as the regions begin to overlap, more rapid recombination would be expected.

It is hoped that it will later be possible to carry this part of the work further, using a vessel large enough and of such shape that either diffusion can be neglected entirely or at least quite accurate corrections can be applied, and that the construction shall be such that the content of the air can be carefully controlled. If in addition provision can be made for varying the intensity of ionization up to values ordinarily used in laboratory experiments, it should be possible to study the conditions under which the term βn is gradually replaced in importance by αn^2.

II.

In connection with the work presented in Section I, various matters came up for consideration and investigation which it seems advisable to present in a separate section, although closely connected with the previous work.

COLUMNAR IONIZATION.

The values taken for q and n_∞ are determined on the assumption that they are uniform throughout the vessel. This requires some consideration. Let us consider the conditions inside a cubical vessel having edges of 30 cms. and a total ionization of 10 ions per c.c. per second, 2.3 being due to α rays, the remainder to β and γ rays. Since one α particle produces about 2×10^5 pairs of ions, an emission of one particle every three seconds is all that is required, and all this ionization is confined to a narrow path about 5 cms. in length. If we assume all the remaining ionization to be due to β particles, that each has a range of 250 cms. and forms 75 pairs of ions per cm. of path, a computation shows that this ionization could be accounted for by β tracks spaced in rows and columns 3.1 cms. apart and running parallel to each other between opposite faces of the cube. The ionization due to γ rays is probably quite uniform but is small in amount.

Jaffé,[15] in his theory of columnar ionization, gives an equation connecting the number of pairs of ions produced per unit length of column and the number still uncombined at any later instant.

[15] *Loc. cit.*

Uncertainty as to the original radius of a column makes it difficult to evaluate, but by setting maximum and minimum limits, it appears that in the case of α tracks it is safe to assume that at least half the ions recombine within one second, while for β tracks there is very little recombination in this interval, or even in much larger intervals of time, and consequently, if the theory applies at all to β tracks, it indicates practically no columnar recombination. Another argument in favor of this conclusion is that if the effect were appreciable for β tracks it would be enormous for α tracks, and this is not the case. It is for these reasons that Plimpton's explanation of his results, as mentioned in the introduction, is considered unsatisfactory.

In view of the facts presented it is evident that the α-ray ionization is far from uniform. That due to β particles is possibly fairly uniform, the columns considered are rather far apart, but there is little columnar recombination and so the ions produced in successive seconds persist for some time.

Table VII includes values of q obtained from the saturation current and also from the initial slope of the corrected n-t curves. A potential of about 400 volts was applied across the chamber. For natural ionization the small difference between the two values of q can be explained on the basis of initial recombination, since the total ionization due to α particles is about 2.3 for fresh outdoor air and less for older air.

About 90 per cent. of the additional ionization produced when radium emanation is introduced into the vessel should be due [16] to α particles. Consequently the increase in q, as obtained from the curves, should be considerably less than that obtained from the saturation current. The increase obtained from the curves was larger than expected, although possibly not unreasonably so.

Additional ionization produced by radium bromide is due to β and γ rays and so should manifest no effect of columnar ionization. The data seem in general to bear this out.

ABSORPTION CENTRES.

A number of questions arose in connection with the consideration of absorption centres, and several subsidiary experiments were carried out. Some of these matters will now be presented.

Number of Absorption Centres Necessary to Account for the

[16] Rutherford, "Radioactive Substances and Their Radiations," p. 581.

β Term.—Assuming that the β term is due to collisions of ions with dust or other particles having negligible velocity, a rough determination on the basis of the dynamical theory of gases shows that 1000 particles per c.c. of radius 8×10^{-6} cm., or 10 of radius 8×10^{-5} cm., or 1 of radius 2×10^{-4} cm. would be sufficient to account for observed values of β. If it were permissible to explain the β term as indicated, it is seen that the number of particles necessary is not excessive. Where the particles are small, having radius 4×10^{-6} cm., for instance, a computation using Stokes' equation shows that the particles would fall only about 6 cms. per day in still air.

Experiments to Determine the Effect upon Recombination Due to the Presence or Absence of Nuclei.—It was found that artificial rain in the ionization chamber, the introduction of smoke, and of live steam, all produced very similar effects. The original purpose in sprinkling the air was to remove dust particles, but evidently great numbers of water particles remained suspended. An attempt was made to remove dust particles by introducing superheated steam, but it appears that the steam became sufficiently supersaturated by cooling to condense upon the ions as well, and remain suspended. Owing to the similarity of results, it is necessary to present only the results obtained by introducing smoke.

A strong jet of smoke was blown into the small galvanized iron vessel for 10 to 15 seconds. Calling the normal current strength unity, the current after introducing the smoke was over 20, but dropped to about 10 after twenty minutes. The potential was then taken off for fifteen minutes. When again applied, the initial current was about 12, diminishing to 6 after ten minutes. After another fifteen-minute wait with the potential off, the current was about 8, diminishing to 5 after five minutes. After an eight-minute wait the current was 7, reaching the fairly constant value of 3 after about twenty minutes.

Several hours later an attempt was made to obtain an n-t curve. It was found that n reached its maximum value in about thirty seconds, and the value was exceedingly low, being roughly 200 ions per c.c. About twenty-eight hours after this, a curve much nearer normal was obtained.

A small puff of smoke was again introduced, and again there

was practically no building up of ions. Air was then pumped through the chamber with a foot bellows, tests of n being made after every few minutes, and after about thirty minutes of pumping there was apparent a small growth in n. After standing for fifteen hours the ionization was very much greater, and after another nine hours it was slightly greater than its value just before the second puff of smoke was introduced. Two days later it was still about the same, n_∞ being 1162 and q, 13.3. Room air was then pumped through the vessel for about three minutes and had the effect of increasing q by 10 or 15 per cent. and decreasing n about 35 per cent.

Explanation of Results.—Eve [17] has shown that introducing smoke has the effect of producing a great number of large slowly moving ions, which owing to their slow motion are not detected in ordinary observations. The large initial current observed above upon introducing smoke was probably due to the gradual clearing out of some of these large ions and so was not a true saturation current. The rapidity with which this current decreased in magnitude would depend upon the mobility of the ions. An increased current after the potential had been removed for a time would be expected, as opportunity was thus given for the small ions to attach themselves to smoke particles instead of being drawn to the walls of the vessel immediately upon formation.

The inability to measure an n in the vessel by the ordinary method is probably due to the rapidity with which the small ions unite with the smoke particles. As the number of smoke particles decreases an increase in the measured n would be expected. This is probably the explanation of the increase of the measured n with time, the smoke particles gradually settling. Pumping air through the vessel would remove some of the smoke particles and this would produce an apparent increase in n, as was found. The decrease in n, found in the case where the vessel had been allowed to stand for some time and then air pumped in, was probably due to the introduction of more dust or smoke than was removed.

After the experiments indicated above, the vessel and insulation were carefully cleaned and dried, the inside covered with glycerin and a large tray of phosphorous pentoxide placed in the bottom. A small fan aided in producing circulation to remove

[17] *Phil. Mag.*, **19**, p. 657 (1910).

dust and moisture. The ionization was first tested before running the fan and even after seven hours the values of n obtained were very low. The fan was then run for about eighteen hours and a considerable increase in the apparent n resulted, the data in Table VII, under date of March 20th, showing the results obtained. The fan ran an additional thirty-seven hours before the observations on the 25th, and twenty-four hours more just previous to the observations on the 29th.

THE EFFECT OF IONIZATION UPON CAPACITY.

We will now consider the relationship between what may be called the "low potential capacity" and the ordinary or high potential capacity of an ionized gas condenser having plates some distance apart. This matter was merely referred to in Section I under "Methods of Measurement."

It was first shown by J. Zeleny [18] that if two plates are placed in an ionized gas and a potential difference established, the field between is stronger in the neighborhood of the plates than at the centre. Thomson [19] discussed the matter for the case where the plates were an infinite distance apart, and Swann [20] extended the calculations to plates at a finite distance. The result is obtained that the ratio of the field at the plates to that at the centre may, for natural ionization in air, reach a maximum value of 2.7[21] for very small applied potentials. For larger potentials the ratio becomes less, approaching unity for fields sufficiently strong to clear out all the ions. It is easily shown that this ratio represents the ratio of the two capacities mentioned above.

Suppose a potential V to be applied across a parallel plate condenser containing an ionized gas. Let C_x be the capacity and Q_x the charge on each plate. In the absence of ions let C be the capacity and Q the charge. Then $VC = Q$ and $VC_x = Q_x$ and so $C_x/C = Q_x/Q$. As the applied potential is made smaller, the region near the plates in which the stronger field exists becomes narrower, and for very small potentials very little error is introduced by assuming that the field intensity half-way between the

[18] John Zeleny, *Phil. Mag.*, **46**, p. 120 (1898).

[19] "Conduction of Electricity through Gases," p. 64.

[20] *Terrestrial Magnetism*, **18**, p. 163 (1913).

[21] 2.7 assuming only recombination of αn^2 type. If α is taken as 50×10^{-6}, the maximum ratio becomes 1.14.

plates is the same, whether or not ions are present. Consequently, if X_c is the field at the centre

$$X_c = 4\pi \frac{Q}{\text{Area}}$$

also

$$X_p = 4\pi \frac{Q_x}{\text{Area}}$$

and so

$$\frac{Q_x}{Q} = \frac{X_p}{X_c}.$$

This ratio we have seen may reach the value 2.7, and this then is the maximum ratio of C_x to C. That is, the effective capacity of a condenser of the type indicated may be 2.7 times as great as would be found by the ordinary methods of measurement.

An experimental determination of the ratio of these two capacities was next undertaken. A sensitive electrometer was necessary and on account of the low ionic velocities it was necessary to surround the ionization chamber with a dead air space to prevent air currents which would destroy the desired state of separation of the ions. A condenser was constructed consisting of a box 130 cms. by 100 cms. by 40 cms. in depth, covered at the top and bottom with galvanized iron plates and rendered conducting on the internal walls by conducting black paper. The central plate was 61 cms. by 82 cms. and was surrounded by a guard ring 10 cms. in width. The high potential capacity measured as in the previous work was 43.8 cms.

The method used in measuring the low potential capacity was such as to make unnecessary any correction for ionization current during the experiment. With the central plate connected to the electrometer it and the guard ring were raised to some small known potential and the potentiometer system A (Fig. 1) so adjusted that there was no current across the condenser. The central plate was then disconnected and earthed, the guard ring earthed, the plate then reconnected and both it and the guard ring restored to the original potential. The potential of the plate was raised by changing the potential V_B across the standard condenser C.

The numerical magnitudes involved in a typical determination will be given. The original known potential was 0.0144 volt or

4.80×10^{-5} e.s.u. corresponding to the deflection of 8 cms. on the electrometer scale. The change in V_B required to restore the plate to the above potential after earthing was 0.0198 volt = 6.60×10^{-5} e.s.u. As the capacity C was 68.5 cms., the quantity of electricity required was 4.52×10^{-3} e.s.u., and dividing this by 4.80×10^{-5} gives 94.3 cms. as the low potential capacity, making the ratio of capacities in this case 2.15.

The potentials used were seldom above and sometimes very much below 0.1 volt. This gives an ionic velocity of less than 0.01 cm. per second; thus very slight air currents would be sufficient to prevent the desired conditions from being established. Consequently, consistent results were not obtained, but in a series of observations extending over fourteen days the ratio was always found to be greater than unity and a few values as high as four were obtained. It is felt that this justifies the statement that the effect exists, and that owing to its magnitude it should be taken into consideration when low potentials are used on gas condensers whose plates are some distance apart.

THEOREM.

While carrying out the experimental work indicated previously, it became desirable to know the effect of momentarily earthing the plates of a condenser containing ions, and the following theorem and proof were developed. *Given a closed condenser of any form with any arbitrary distribution of positive and negative ions between its plates. To prove that if the two plates are momentarily earthed and the ions then allowed perfect freedom, in the final state the plates will be at zero potential.*

In the final state there are no charges in the region between the conductors, because if there were, there would be a flux across a surface enclosing them proportional to the enclosed charge. The charges would consequently leave the region.

At the initial instant the conductors take such charges as are necessary to give them zero potential. Consequently in the field which exists due to charges between the plates, there must be at least one surface where the field reverses direction, *i.e.*, becomes zero. By Gauss' theorem the total charge inside this surface is zero. Therefore the volume charge on either side of the surface is equal and opposite to the charge on the neighboring conductor. No charges cross the surface and in the final state no charges

remain in the volume. Consequently these charges neutralize each other, leaving no charges anywhere, and so the conductors are at zero potential.

SUMMARY.

The various methods of determining the coefficient of recombination are briefly indicated, and the general results previously obtained are given.

The coefficient of recombination of ions in air was determined for ions produced by "natural" ionization as opposed to the strong "artificial" ionization usually used in laboratory experiments.

McClung's method, used for some of the observations, was replaced by a new method which requires the measurement of the growth with time of the number of ions per c.c. The diffusion correction is based upon a solution obtained for the equation

$$\frac{\partial n}{\partial t} = D\frac{\partial^2 n}{\partial x^2} - \beta n + q.$$

Results of the present investigation substantiate Von Schweidler's conclusion that for natural ionization in atmospheric air it is more appropriate to determine a recombination coefficient β, depending upon the first power of the number of ions, than to determine an α depending upon the square of this number. The present work also extends this conclusion to the case of confined air subject to various intensities of ionization by α and β rays up to about 400 ions per c.c. per second, and various degrees of purity of the air. It applies also to the case where precautions were taken to remove moisture and dust particles. The value of β was found to be quite constant, averaging about 6×10^{-3} when the ionization intensities and dust content were low. These results show that a recombination depending upon the first power of the number of ions cannot be explained by the presence of dust and moisture. A suggested explanation is that it is due to a non-uniform distribution of ions.

The non-uniform distribution of ions resulting from natural ionization is discussed, and results of a few experiments on columnar ionization given.

A computation based upon the dynamical theory of gases shows that only a comparatively small number of dust particles would be necessary to account for the β term if it were permis-

sible to assume it as due to this cause. The large currents and low values of n, obtained by introducing artificial rain, smoke and steam into the ionization chamber, are explained as due to the production of large slowly moving ions.

Theoretical considerations supported by experimental results show that for low potentials the capacity of an air condenser having the plates some distance (20 cms.) apart, may be increased by the factor 2.7, by natural ionization.

A proof is given for a theorem which states that if the plates of a closed condenser are momentarily earthed, they will in the final state be at zero potential, no matter what the original distribution of ions may be.

In conclusion the writer wishes to express his indebtedness to Professor W. F. G. Swann for suggesting this problem and for his advice and assistance during the progress of the work, and also to Professor J. T. Tate for his assistance and encouragement.

A New Measurement of the Pressure of Radiation. W. GERLACH and ALICE GOLSEN. (*Z. f. Phys.*, vol. 15, No. 1.)—Let it be remembered that Bartolini predicted the existence of a pressure exerted by radiation upon a surface on which it impinges, that Peter Lebedew demonstrated its existence and that Nichols and Hull, at Dartmouth College, measured it with great care. The present investigators set out to make an independent measurement at pressures of surrounding gas so low that nothing akin to radiometer action could complicate the results. A sheet of thin platinum foil was suspended so as to hang to one side of a quartz thread. A beam of light struck the foil and made it turn around the thread as an axis. First a study of the deflections produced by the beam at different gas pressures had to be made. Strangely enough, for the pressure interval from 1 mm. to 2×10^{-4} mm. the foil moved toward the light instead of away from it. As the pressure is reduced the foil shows a push which reaches a maximum at 10^{-5} mm. Further reduction causes a slight lessening of radiation pressure as indicated by angular deflection. Finally the force exerted by the beam became independent of the gas pressure, and there was almost no damping of the oscillations.

These results are given:

1. In a vacuum of from 10^{-6} to 10^{-7} mm. of mercury a constant residual reflection is found, which is interpreted to be due to nothing but the pressure of the incident radiation.
2. This deflection is proportional to the incident energy and is independent of the wave-length of the radiation.
3. The pressure of radiation calculated from the residual deflection agrees within 2 per cent. of the theoretical value.

G. F. S.

THE SHORT-WAVE RADIATION FROM TUNGSTEN FILAMENTS.*

BY

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I. INTRODUCTION.

RADIATION of short wave-lengths is becoming more important each year as studies and applications of radiations increase in extent and number. At the present time the spectral regions of most practical importance are those whose spectral limits are established by the transmission of the atmosphere, of glasses and of quartz. The limit of the spectrum of solar radiation [1] is determined by the contents of the upper atmosphere, apparently, chiefly by ozone. The practical limit is about 295 mμ, although it is not difficult to record 292 mμ photographically. By means of a quartz spectrograph the last indication of photographic action is found to be at about 290 mμ. The photoelectric cell has recorded solar radiation as short as 280 mμ in wave-length.

Some glasses transmit approximately as far as the short-wave spectral limit of solar radiation, but the transmission limit is shortened in general as the refractive index of the glass increases. For example, a glass of refractive index of 1.51 transmitted to 295 mμ; a light flint of refractive index of 1.57 transmitted to 305 mμ; and a very dense flint glass of refractive index of 1.69 transmitted only to 335 mμ. However, content also determines the limit of transparency. Owing to the fact that some glasses of low refractive index transmit energy of wave-lengths as short as 295 mμ, a continuous-spectrum source confined in such a glass supplies radiation similar to solar radiation in spectral extent, though not necessarily in spectral distribution of energy.

The limit of transparency of quartz varies somewhat, depending upon the specimen; furthermore, natural quartz crystals are generally transparent further into the ultra-violet than fused quartz. The latter is transparent to 185 mμ, although a practical limit may be considered to be at about 200 mμ.

* Communicated by the Director of the Laboratory.

For convenience the term "near ultra-violet" is given to the region between 300 mμ and 400 mμ and the term "middle ultra-violet" to that between 200 mμ and 300 mμ. The "extreme" region of wave-lengths shorter than 200 mμ includes the radiations readily absorbed by air and most other media, and also includes gamma rays and X-radiation. The extreme region is of great scientific interest, but is of comparatively little practical interest at the present time.

A great many materials, including solids, liquids, and some gases of appreciable thickness, are transparent only to the near ultra-violet. Among these are mica, "celluloid," diamond, Canada balsam, ether, glycerin, acetone, turpentine, xylene, and many ordinary glasses. Fewer media are transparent to the middle ultra-violet. Among these are rock-salt, fluorite, alum, gypsum, sugar, calcspar, water, ethyl alcohol, glacial acetic acid, liquid ammonia, and fused and crystalline quartz. Of course, the limit of transparency depends upon thickness as well as upon the medium itself so that the foregoing statements are subject to qualifications.[1]

However, it is evident that, from a practical standpoint, the spectral transmission limits of glasses and of many other materials make the near ultra-violet of interest. Likewise, the transparency of quartz for the middle region (as well as for the near ultra-violet and visible regions) makes this middle region also of practical interest.

It has been fairly well established that it is the ultra-violet radiation of wave-length shorter than 305 mμ that is quite injurious to living cells.[2] Fortunately the cornea of the eye is opaque to radiations shorter than about 295 mμ, thereby protecting the eye-media from the more dangerous rays. The lens is opaque to radiations shorter than 350 mμ in wave-length, therefore, it may be safely stated that the retina does not receive appreciable amounts of energy of wave-lengths shorter than 350 mμ.

The point in the spectrum at which germicidal action begins has not been established with certainty. Doubtless it varies with the kind of living organism, but in general it is near 300 mμ. Certainly it is within the limit of the solar spectrum, because it is well known that solar radiation is germicidal. Bovie[3] found that radiation of wave-lengths shorter than 292.5 mμ killed bacteria and spores of various fungi in ten minutes, but radiation of 295 mμ

did not kill for two hours. Browning and Russ [4] found 296 mμ to be the long-wave limit of germicidal action. Obviously time and intensity are important factors and in the case of solar radiation we have long periods of exposure and intensities of certain radiations not often equalled by artificial means.

It is obvious that another region of importance is that between the vicinity of the spectral limit of solar radiation and of transmission of glasses which probably includes the long-wave limit of general germicidal action. In other words, the region between 290 mμ and 310 mμ is of special interest.

One of the rapidly growing fields of application of ultra-violet and visible radiations is that of therapeutics. Unfortunately many of these applications are made without an accurate record of spectral limits and of spectral distributions of energy. Furthermore, many of the data are conflicting; however, the therapeutic values of these radiations have been established.[5]

The increasing number of photochemical reactions and the increasing use of photographic processes add to the interest in short-wave radiation.

The foregoing brief glimpse indicates why it is of interest to study any practical radiant which supplies ultra-violet radiation. Some studies have been devoted to the short-wave region of the radiation from the tungsten filament, but certain desirable data as to the relation of temperature to such factors as spectral limit and photographic action have not been available. Furthermore, it appeared desirable to extend the study of the limits of spectral transmission of glasses which was made by one of the authors quite a number of years ago in connection with the development of a filament lamp for photographic purposes.[6] At that time the various glasses were studied and a blue bulb was developed which greatly reduced the visible radiation without appreciably impairing the photographic values of the total radiation for most photographic plates and films. Furthermore, a higher operating temperature was adopted for the filament, which was more consistent with the various economic factors involved. During those investigations the interesting discovery was made that by adding a slight amount of cobalt oxide to a certain glass "mix," the limit of spectral transmission was extended appreciably further into the ultra-violet, that is, to a shorter wave-length. Inasmuch as this spectral limit is close to those wave-lengths where germicidal action and

destruction of living cells begins, this point is of particular interest. Some years later this effect of cobalt oxide was verified.[7]

There are various practical ways of studying the ultra-violet radiation from tungsten filaments, but in the present work photography was chosen because photographic value was one of the aims of the investigations. In the spectral work, quartz spectrographs were used entirely. Special filament-lamps were made with quartz windows at the end of a one-inch tube which extended several inches from the side of the bulb. Temperature measurements were made by means of an approved pyrometric method and the photographic action was studied by approved photometric methods. The work is presented in condensed form under several subheads into which it has been divided for presentation.

II. NOMENCLATURE AND DEFINITIONS.

The nomenclature of photography dealing with the exposure and blackening of photographic emulsions has been found by the authors to be meagre and inadequate. For this reason they have introduced certain new terms.[16] The definitions of these and some definitions adopted by the Illuminating Engineering Society are presented in paragraphs which follow.

A *radiator* is a body or object emitting radiant energy.

Intensity of radiant flux or *flux density* is the quantity of energy which traverses, in the unit of time, a unit surface normal to the direction of propagation. It may be expressed in ergs per square centimetre per second.

The *international candle* is the unit of luminous intensity, such as has resulted from international agreement between the three national standardizing laboratories of France, Great Britain and the United States in 1909.

A *lumen* is the unit of luminous flux. It is equal to the flux through a unit solid angle (steradian) from a uniform source of one international candle.

A *metre-candle* (or lux) is the unit of illumination (visual) as used in this paper. It is equal to one lumen per square metre, or it is the direct illumination on a surface which is everywhere one metre distant from a point source of one international candle.

Exposure is the time integral of intensity of radiant flux. In this paper exposure is expressed in three ways, as follows:

(*a*) In ergs per square centimetre.

(*b*) In metre-candle-seconds (luminous efficiency being known).

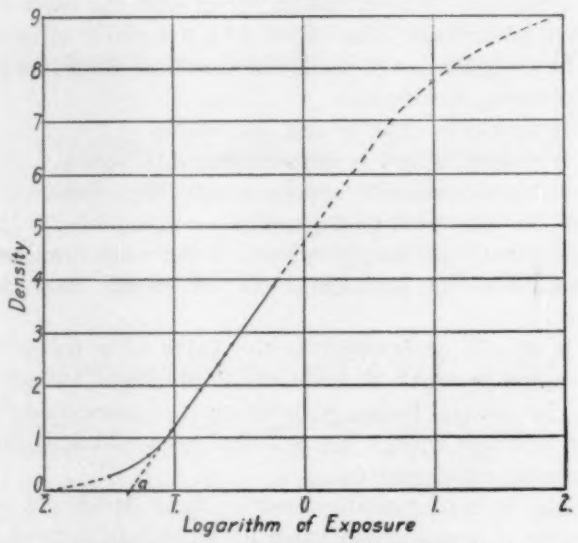
(*c*) In seconds (intensity of radiant flux being assumed known or constant).

Optical density (D) is defined as $\log_e \frac{1}{T}$, where T is the transmission-factor, measured visually, for energy from a diffuse radiator.

$$D = \log_e \frac{1}{T} = -\log_e T, \text{ or } T = \frac{1}{e^D}$$

where e is the base of the natural logarithms. The transmission-

FIG. 1.



Typical exposure-density curve of a photographic emulsion.

factor is customarily determined relatively to that of an unexposed adjacent portion of the plate, usually called a fog-strip.

Exposure-density Curves.—If different portions of a photographic emulsion are exposed to radiant energy of constant intensity for varying lengths of time, and the resultant densities of these portions are plotted as ordinates and logarithms of exposures as abscissæ, the result is an S-shaped curve having a straight-line portion (Fig. 1). The exposure corresponding to the point of intersection (*a*) of the tangent to the straight-line portion with

the exposure axis is usually designated as the *inertia* of the emulsion for the particular radiations used. This curve is called an *exposure-density curve.*

Sensitivity (S_λ) of a photographic emulsion to monochromatic radiations of wave-length λ is defined, for the purposes of this paper, as the reciprocal of the inertia in ergs E_λ incident upon one square centimetre of emulsion. Hence sensitivity for wave-length λ is

$$S_\lambda = \frac{1}{\text{Inertia in ergs of wave-length } \lambda} = \frac{1}{E_\lambda}.$$

The *spectral-sensitivity curve* of an emulsion is a curve showing the sensitivity S_λ for each wave-length throughout the spectrum.

The sensitivity of an emulsion varies with the wave-length of the incident radiations. The choice of a numerical value of sensitivity to be assigned to any particular emulsion should be governed by the following desiderata:

(*a*) It should be definite and practicable.

(*b*) It should be easy to determine and to verify.

(*c*) It should indicate approximately the relative speeds of emulsions for practical photography.

(*d*) It should be simply related to the maximum sensitivity of the emulsion for monochromatic or nearly monochromatic radiations.

(*e*) It should correspond to the value at a wave-length or spectral region in which all commercial emulsions are sensitive.

(*f*) The spectral region with which it is associated should be such that sufficient energy for practical tests is readily obtainable from ordinary light-sources.

Possible ways of meeting most of these desiderata would be the adoption of a numerical value of sensitivity defined in some one of the following ways:

(1) The maximum sensitivity in the violet region of the visible spectrum.

(2) The sensitivity for some standard wave-length, *e.g.*, 436 mμ of the mercury spectrum.

(3) The average sensitivity over the selected spectral region from 350 to 450 mμ, in which region the sensitivity of many emulsions is fairly uniform and practically the maximum.

(4) The average spectral sensitivity of the emulsion over its most effective region.

(5) The average sensitivity to solar radiation at noon, or to some standard heterogeneous source.

As a practical value of the *sensitivity S of an emulsion* which more nearly satisfies the majority of the above desiderata, we adopt for use in this paper the average sensitivity of the emulsion for a narrow spectral region having its average value at about the wave-length of the mercury line 436 mμ.

Therefore the *sensitivity* S of an emulsion is defined as the reciprocal of the inertia in ergs, E, incident upon one square centimetre of the emulsion of practically monochromatic radiation of wave-length 436 mμ, or

$$\textit{Sensitivity, } S = \frac{1}{\text{Inertia in ergs of wave-lengths about } 436\ \text{m}\mu} = \frac{1}{E}$$

Actinicity, A, of any radiation is defined as the reciprocal of the inertia in ergs, E_r, incident per square centimetre of the emulsion, or

$$\textit{Actinicity, } A = \frac{1}{\text{Inertia in ergs of this radiation}} = \frac{1}{E_r}$$

Photographic efficiency, ρ, of any radiation upon an emulsion is defined for the purposes of this paper as the ratio of the inertia in ergs, E, of the standard radiation of practically 436 mμ in wave-length to the inertia in ergs, E_r, of this particular radiation, or

$$\textit{Photographic efficiency, } \rho, = \frac{E}{E_r} = \frac{A}{S} = \frac{\text{Actinicity}}{\text{Sensitivity}}$$

If a photographic emulsion is exposed to radiant energy from an incandescent radiator at various temperatures, less time is required for equal blackening of the emulsion at high than at low temperatures of the radiator. This difference is the result of differences in intensity and actinicity of the radiant energy. Since the effectiveness of the radiant energy in blackening the emulsion is proportional to the reciprocal of the inertia in seconds, *photographic effectiveness* of any radiation of flux density J is defined as the reciprocal of the inertia in seconds for an emulsion of sensitivity S, or

$$\begin{aligned}\textit{Photographic effectiveness, } Q &= \frac{1}{\text{Inertia in seconds}} = \frac{1}{t} \\ &= \frac{\text{Flux density in ergs per second}}{E_r} \\ &= \text{Flux density} \times \text{efficiency} \times \text{sensitivity}\end{aligned}$$

As may be seen by reference to Fig. 13, the sensitivity curves of a photographic emulsion and a normal eye vary greatly, being quite different in shape and affected by radiations of more or less different wave-lengths. Therefore it is evident that exposures given in terms of visual sensations for radiations of different spectral distributions of flux density give no *direct* measure of intensity of energy incident upon the emulsion. For this reason exposures and inertias given in metre-candle-seconds are faulty measures of energy, and all factors when so expressed will be preceded by the word *pseudo*, indicating false; thus,

Pseudo-actinicity of any radiation is defined as the reciprocal of the inertia, in metre-candle-seconds, of radiation incident upon the emulsion of sensitivity S, or

$$\textit{Pseudo-actinicity}, A_p = \frac{1}{\text{Inertia in metre-candle-seconds}}$$

If a radiator of area A, of a brightness of B candles per square centimetre, radiates W watts from each square centimetre of radiator at a luminous efficiency of L lumens per watt, then an emulsion placed d centimetres from the radiator and normal to the direction of propagation will in t seconds receive E_r ergs per square centimetre, or $E_r = \frac{AWt}{4\pi d^2} \times 10^7$ ergs per square centimetre.

Now since total lumens $= \pi BA$, the lumens per watt, $L = \frac{\pi BA}{AW}$ $= \frac{\pi B}{W}$. Therefore, substituting for W from this equation, we have

$$E_r = \frac{A\pi B 10^7 t}{4\pi d^2 L} = \frac{A\pi B}{4\pi\left(\frac{d}{100}\right)^2} t \frac{10^7}{(100)^2 L}$$

$$= (\text{metre-candle-seconds}) \times \frac{10^5}{L} \text{ in ergs per square centimetre}$$

Hence, exposures expressed in metre-candle-seconds may be converted into exposures expressed in ergs per square centimetre by multiplying by the factor $\frac{10^5}{L}$. This is the energy which would reach the emulsion if the interposed medium reduced the total energy of all wave-lengths in the same proportion as it reduces the energy which produces visual sensation.

Temperatures in this paper are expressed in degrees Kelvin, °K.

III. ACTINICITIES OF RADIATION FROM TUNGSTEN AT VARIOUS TEMPERATURES THROUGH VARIOUS MEDIA AS MEASURED BY FOUR REPRESENTATIVE PHOTOGRAPHIC EMULSIONS.

The relative photographic efficiencies of various radiants have previously been studied by the authors and others.[8] This investigation was conducted for two primary purposes: (1) To determine the change of actinicity of the radiation from incandescent tungsten with temperature of the tungsten; (2) to determine the decrease of actinicity of the radiation after traversing specimens of glass (chiefly those used in tungsten-filament lamp-bulbs). The development of the plates was standardized and maintained so throughout all the investigations. Its details are not important from the standpoint of the aims of the investigation.

Apparatus and Methods.—The photographic apparatus employed in this investigation consisted of the following parts arranged along a photometer bar in the order mentioned below:

(1) A specially constructed 1000-watt, 30-ampere, U-shaped tungsten-filament in a gas-filled "hard" glass bulb fitted with a quartz window; (2) a quartz lens for collecting and focusing the light; (3) an iris diaphragm and a shutter for use in controlling the length of exposures; (4) a rough-ground fused-quartz plate on which the image of a portion of the filament was focused; (5) several black-velvet screens which effectually intercepted and absorbed all extraneous light; (6) a rotating multi-sectored disc with ten different angular openings which gave eleven different exposures per strip upon the photographic plate; (7) a slit of ⅜-inch width lengthwise of the photographic plate; (8) a plate-holder which could be adjusted to any position with reference to the slit.

Six exposure strips made under varying conditions were obtained on each plate. Approximately identical strips were obtained by suitably varying the exposure when the test conditions were varied. The reciprocity law has been assumed, *i.e.*, that under any particular conditions, the plate density produced is a function of the product of radiant flux density and exposure time, and is independent of the relative values of these factors. This assumption is not rigidly correct, but is approximately so under the conditions of the tests.

The true absolute temperatures of the lamp filament were measured by optical pyrometer methods by Dr. W. E. Forsythe

of the Laboratory of Pure Science for various temperatures up to about 3400° K. Standardized potentiometers were used for measuring the current through the lamp filament, and the intensity of illumination at the plate was measured by a photometer. The lamp, diffuser and other apparatus were rigidly connected together upon a carriage which could be moved to any desired distance from the photographic plate, and by employing the law of inverse squares any intensity of illumination upon the photographic plate could be obtained and calculated with precision.

The apparatus for measuring the densities of the photographic negatives consisted of: (1) An integrating sphere illuminated within to a constant brightness; (2) a movable constant-intensity comparison lamp which illuminated a milk-glass diffusing surface; (3) a bi-prism and two 45° prisms which reflected the two beams at right angles. The light from one of these beams traversed the exposed portion of the negative and the other beam traversed the " fog-strip " of the negative. The apparent brightnesses of these two surfaces were brought to an equality by moving the comparison lamp, and, when necessary, by using a rotating sectored disc in the path of one or the other of the beams.

Types of Emulsions.—The photographic emulsions employed were standard 4" × 5" dry plates manufactured by the Eastman Kodak Company, and were of the following types:

(*a*) Seed's No. 26, of emulsion No. 5431.

(*b*) Seed's No. 23, of emulsion No. 4880.

(*c*) Standard orthonon, extremely rapid, of emulsion No. 4338.

(*d*) Wratten and Wainwright panchromatic, sensitive to red light, of emulsions Nos. 3310 and 3404.

Glasses Tested.—The glass and other transmission media employed were as follows:

(1) A specimen of type No. 5 soft glass, about 0.91 mm. thick. This is a soda-lead glass with 20 per cent. lead oxide.

(2) A specimen of Pitney lime glass about 0.95 mm. thick. This is a soda-lime glass with 17 per cent. sodium oxide, 10 per cent. calcium and magnesium oxides, and balance of silica.

(3) A specimen of G 702 P hard glass about 0.96 mm. thick. This is a boro-silicate glass of the " pyrex " type.

(4) A specimen of bulb of the Mazda C-2 daylight lamp,

about 0.96 mm. thick. This is the same as (1), type No. 5, but contains certain coloring ingredients.

(5) A specimen of bulb of the Mazda C-3 photographic lamp, about 0.95 mm. thick. This is the same as (1), type No. 5, but contains certain coloring ingredients.

(6) A specimen of quartz about 1.5 mm. thick.

(7) A specimen of quartz about 1.5 mm. thick with a sufficiently thick deposit of tungsten metal to reduce its transmission in the visible to about 9.8 per cent.

Results.—Exposure-density curves were made for the five types of bulb-glass, with each type of photographic plate and over wide variations in temperature of filament; and from them was determined the pseudo-actinicity corresponding to each temperature.

Approximately 4 per cent. of the light incident upon a specimen of clear glass in air is reflected from each surface, but, with a lamp-bulb made of this same kind of glass, practically no light is finally lost on account of reflections. In order to reduce all data to a comparable basis an allowance of 8 per cent. for reflections from the specimens has been made in all cases, since this 8 per cent. actually was lost under the test conditions. Hence, neglecting experimental errors, observed differences of pseudo-actinicities at any temperature are due only to differences in amount and character of the absorption of the incident radiations by the interposed media.

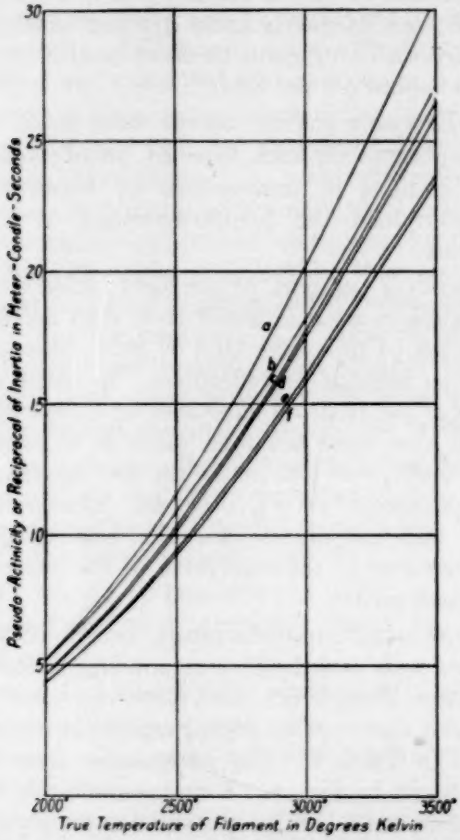
From pseudo-actinicity-temperature curves obtained experimentally, values were scaled off corresponding to temperatures of 2000, 2200, 2400, 2600, 2800, 3000, 3200 and 3400° K. for each type of glass and each type of photographic plate, and these have been tabulated in Table I. The comparative data for a Seed's 26 plate are shown in Fig. 2. Pseudo-actinicities for the same emulsion based on metre-candles measured at the plate with glasses interposed are shown in Fig. 16.

A study of the effect of blackening or deposit on lamp-bulbs during the operation of tungsten lamps was made to determine whether this deposit is selective in transmission. It was found to be only slightly selective, that is, the decrease due to a normal deposit on the inside of lamp-bulbs was only slightly greater for actinic radiations than for luminous radiations. However, a very

dense deposit which reduced the luminous radiations to 9.8 per cent. reduced the actinic radiations to approximately 5.8 per cent.

Inherent in photography, measurements of illumination, temperatures and optical densities, there are numerous variables

FIG. 2.



Pseudo-actinicity (1 ÷ inertia in metre-candle-seconds) curves for radiant flux from tungsten as effective on Seed's 26 plates, illumination being measured at the plate without the glass interposed, and deducting 8 per cent. for reflections when the glasses are interposed. (*a*) Quartz; (*b*) soda-lead; (*c*) soda-lime; (*d*) boro-silicate; (*e*) C-2 daylight; (*f*) C-3 photographic.

and experimental errors which affect the determinations. Since considerable care has been exercised in controlling these variables, it is believed that the results are substantially correct, though containing a few minor inconsistencies.

TABLE I.

Table showing values of pseudo-actinicity of radiations from incandescent tungsten at various temperatures through various media upon four types of emulsions, the metre-candles upon the emulsions being measured without the glass specimens interposed and deducting 8 per cent. for reflections by the interposed glass. The pseudo-actinicities are the reciprocals of the inertias which are expressed in metre-candle-seconds.

Interposed medium.	Pseudo-actinicities or reciprocal of inertias in metre-candle-seconds for temperatures indicated.							
	2000° K.	2200	2400	2600	2800	3000	3200	3400° K.
Seed's 26 Plate								
Quartz	5.2	7.4	10.0	13.0	16.4	20.1	24.2	28.4
Soda-lead	4.7	6.6	9.0	11.7	14.5	17.7	21.1	24.7
Soda-lime	5.2	7.2	9.6	12.2	15.1	18.2	21.6	25.2
Boro-silicate	4.4	6.0	8.1	10.4	13.0	15.8	18.8	21.9
C-2 daylight (light blue)	4.7	6.6	8.9	11.5	14.3	17.5	20.8	24.3
C-3 photographic (dark blue)	4.4	6.1	8.2	10.6	13.2	16.1	19.1	22.2
Seed's 23 Plate								
Quartz	2.4	3.2	4.2	5.4	6.7	8.1	9.7	11.3
Soda-lead	2.2	3.0	4.0	5.1	6.3	7.7	9.1	10.6
Soda-lime	2.3	3.1	4.1	5.2	6.5	7.8	9.4	10.9
Boro-silicate	2.1	2.9	3.8	4.9	6.1	7.4	8.9	10.4
C-2 daylight (light blue)	2.0	2.8	3.8	4.9	6.2	7.5	9.0	10.5
C-3 photographic (dark blue)	2.0	2.8	3.9	5.0	6.3	7.7	9.2	10.8
Orthonon Plate								
Quartz	6.4	8.4	10.9	13.6	16.5	19.8	23.4	27.3
Soda-lead	5.2	7.3	9.8	12.5	15.5	18.7	22.3	26.0
Soda-lime	6.2	8.0	10.0	12.4	15.0	17.8	20.8	24.0
Boro-silicate	4.7	6.3	8.3	10.5	12.9	15.6	18.5	21.5
C-2 daylight (light blue)	5.2	7.1	9.3	11.8	14.6	17.6	20.9	24.2
C-3 photographic (dark blue)	4.8	6.6	8.6	10.9	13.5	16.3	19.3	22.5
Panchromatic Plate								
Quartz	2.3	3.1	4.1	5.2	6.4	7.7	9.1	10.6
Soda-lead	2.1	2.9	3.8	4.9	6.1	7.4	8.9	10.4
Soda-lime	2.2	3.0	4.0	5.1	6.3	7.6	8.9	10.4
Boro-silicate	2.1	2.7	3.4	4.3	5.2	6.2	7.4	8.6
C-2 daylight (light blue)	2.2	2.7	3.4	4.2	5.1	6.1	7.2	8.3
C-3 photographic (dark blue)	1.9	2.3	2.8	3.4	4.0	4.8	5.7	6.6

IV. SPECTRAL TRANSMISSION OF THE VARIOUS LAMP-BULB GLASSES.

The glasses studied are described in Part III but the thicknesses differ, being as follows:

Type of Glass.	Thickness.
No. 5 soda-lead	0.84 mm.
Pitney lime	0.80
Hard glass, G702P	1.05
Mazda C-2 daylight bulb	0.47
Mazda C-3 photographic bulb	0.52

Apparatus and Method.—The apparatus consisted of the following: A quartz prism spectrograph; a quartz lens; a diffusely transmitting quartz plate; a quartz tube mercury lamp; a special tungsten lamp with quartz window and a 20-mil. filament in gas; sectored discs; dividing engine; Marten's polarization photometer with 0.5-mm. slit through which the exposed photographic plate was viewed when measuring the densities of the silver deposit.

Three methods were employed in making the determination of spectral transmission:

(1) By the use of the special tungsten lamp continuous spectra were obtained. Exposures for different lengths of time were made with and without the specimens of glass interposed. The photographic plates were measured for density, and exposure-density curves plotted for various wave-lengths throughout the spectrum. From these curves inertias (expressed in time units only) were obtained. The ratio of observed inertias without and with the bulb-glass interposed, for any particular wave-length, gives the transmission of the glass for that wave-length. This method involves a great deal of labor, and is subject to many errors. The results obtained were of value, but not as satisfactory as desired.

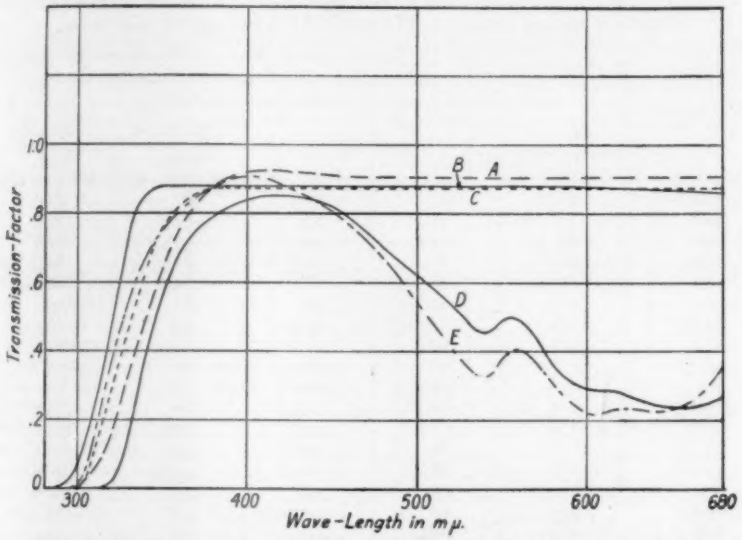
(2) By using a spectrophotometer, with visual observation, transmission factors were obtained for each type of glass for the spectral region from 420 mμ to 700 mμ. Values obtained by this method for wave-lengths below 460 mμ were somewhat uncertain, on account of the low illumination in the photometer field, but were quite satisfactory throughout the remainder of the region measured.

(3) This was also a photographic method. Using the quartz spectrograph, adjacent exposures were made on photographic plates. Alternate exposures were made with the bulb-glass interposed between the lamp and the quartz diffuser placed just in front of the spectrograph slit, and the other exposures were made with the bulb-glass removed. By means of the polarization photometer the point in the spectrum at which two adjacent exposed strips were of equal density was determined, and the corresponding wave-length found by reference to the quartz mercury spectrum on the plate. If t' is the exposure in seconds with the bulb-glass interposed, and t'' the exposure without the glass, then the trans-

mission-factor at the point of equal density of silver deposit is $\frac{t''}{t'}$. This method yields satisfactory results for transmissions on the steep part of the transmission curve, but is not sensitive over portions of the curve where the transmission is changing slowly.

In order to make the transmission data for the various glasses comparable, the observed values have been adjusted by the method devised by one of the authors,[14] to give transmissions for glasses

FIG. 3.



Spectral transmission curves for lamp-bulb glasses 0.8 mm. thick: (*A*) Boro-silicate hard glass; (*B*) soda-lime; (*C*) soda-lead; (*D*) Madza C-2 daylight; (*E*) Madza C-3 photographic.

of a uniform thickness of 0.8 mm. The adjusted values are given in Fig. 3 and Table II, without any correction for reflection.

SPECTRAL LIMITS OF GLASSES AND LENSES.

Many years ago one of the authors[7] found that the limit of spectral transmission of a soda-lead glass was extended farther into the ultra-violet when cobalt was added. This is clearly illustrated in Fig. 4, in which each pair of spectra for clear and cobalt glass was obtained by simultaneous exposure, using an iron arc, a quartz mercury arc and a quartz spectrograph. The various pairs were for different exposures.

In Fig. 5 are given spectrograms of some glasses used in this investigation. These spectrograms were obtained by the use of a

quartz spectrograph, with slit about 0.5 mm. wide (so that density measurements could be made) and a quartz mercury lamp.

In Fig. 6 are given spectrograms of glasses like most of those in Fig. 5, but of a uniform thickness of approximately 0.8 mm. In this spectrogram are also included two glasses like the ordinary Mazda C-2 daylight and Mazda C-3 photographic glasses, except that they are made up by the addition of coloring material to the

TABLE II.

Table of transmissions of lamp-bulb glasses for wave-lengths in the visible and near ultra-violet regions for glasses of a uniform thickness of 0.8 millimetre.

Wave-length in mμ.	Spectral transmission of lamp-bulb glasses 0.8 mm. thick.				
	No. 5 soda-lead.	Soda-lime.	Boro-silicate.	Mazda C-2 daylight bulb.	Mazda C-3 photographic bulb.
300 mμ	.01	.07	.005	.0	.015
320	.28	.47	.15	.017	.365
340	.62	.845	.49	.375	.665
360	.82	.88	.745	.675	.805
380	.875	.88	.875	.785	.875
400	.875	.88	.92	.84	.91
420	.875	.88	.925	.85	.885
440	.875	.88	.915	.84	.84
460	.875	.88	.905	.79	.77
480	.875	.88	.905	.70	.67
500	.875	.88	.905	.62	.545
520	.875	.88	.905	.535	.41
540	.875	.88	.905	.455	.325
560	.875	.88	.905	.495	.405
580	.875	.88	.905	.36	.305
600	.875	.88	.905	.29	.22
620	.875	.875	.905	.28	.235
640	.875	.87	.905	.245	.225
660	.875	.865	.905	.235	.25
680	.875	.86	.905	.27	.36

soda-lime glass instead of the soda-lead which is ordinarily used. Four spectrograms of commercial photographic lenses are also given. The iron arc was used and quartz mercury arc spectra are shown for comparison.

In Fig. 7 are given spectrograms of a tungsten filament at a temperature of 3000° K., with varying lengths of exposure. An examination of the negative for the 15-minute exposure shows that blackening of the plate extends to about 230 mμ.

The spectrograms shown in Fig. 6 and other similar ones have been scaled to determine the extent of the transmission of ultra-

violet radiations by the various glasses and lenses. The results obtained are given in Table II A.

V. SPECTRAL SENSITIVITIES OF FOUR TYPES OF PHOTOGRAPHIC EMULSIONS.

Spectral sensitivities of the four types of photographic emulsions described in Part III have been determined for various wave-lengths throughout the spectral region between 280 mμ and 580 mμ. A series of exposures was made upon a Seed's 23 emul-

TABLE II A.

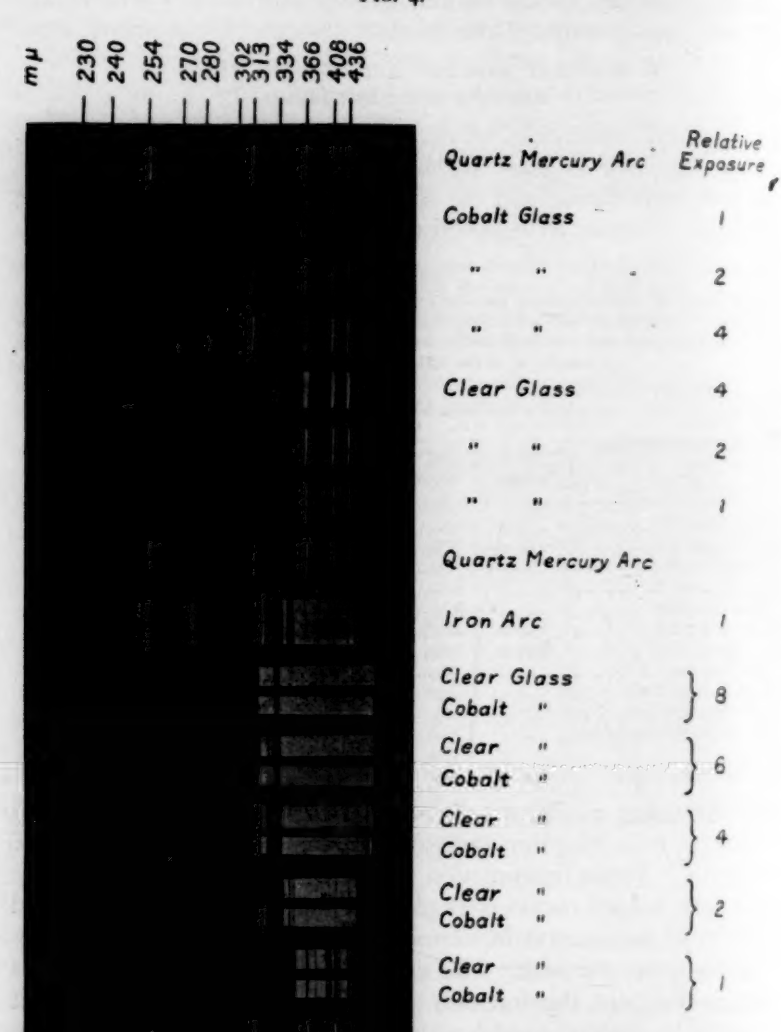
Table showing approximately the shortest wave-lengths of radiation from an iron arc that have traversed various absorbing media and the quartz optical system of a Hilger spectrograph and that are sufficiently strong to make observable lines upon a Seed's 23 emulsion in the exposure times indicated.

Interposed media.	Shortest wave-lengths, in mμ, of radiations producing observable lines.					
	½ min.	1 min.	2 min.	3 min.	4 min.	5 min.
Soda-lead	.....	.....	295.4	295.4	295.0	294.2
Soda-lime	.....	.....	288.4	284.0	283.2	282.3
Boro-silicate	.....	.....	298.4	.....	.....	.....
C-2 soda-lead	.....	.....	304.2	.....	.....	.....
C-2 soda-lime	.....	.....	302.0	.....	.....	.....
C-3 soda-lead	296.0	295.4	295.0	294.2	294.2	294.2
C-3 soda-lime	294.2	293.8	292.9	292.9	292.5	291.8
*Cooke lens	.....	.....	321.4	321.2	321.2	.....
Zeiss Tessar lens	.....	.....	320.0	319.7	319.7	.....
Std. Opt. Co. lens	.....	.....	339.3	339.3	337.0	.....
B. and L. Protar lens	.....	.....	330.6	330.6	330.6	.....

*Made by Taylor, Taylor and Hobson.

sion by using a quartz spectrograph to disperse the continuous spectrum of a tungsten radiator maintained at a temperature of 3060° K. From transmission measurements upon this emulsion, exposure-density curves were plotted; and by the method described in Part II the inertias in seconds corresponding to various wave-lengths were obtained. The dispersion of the spectrograph was determined and the intensity of radiant flux for incandescent tungsten at various wave-lengths was computed by use of equation (13) described in Part VI, where T_c, the color temperature of tungsten at 3060° K., is 3140° K. Hence, knowing the relative inertias of this emulsion at various wave-lengths of the continuous spectrum of tungsten at 3060° K., the dispersion of the spectrograph, and the intensity of radiant flux throughout the tungsten spectrum, the relative sensitivities for this emulsion for a uniform

FIG. 4.



The transmission of clear and cobalt glasses for ultra-violet radiation of bare iron arc and quartz mercury arc.
(From "Ultra-violet Radiation" by M. Luckiesh.)

distribution of radiant flux were computed for various wave-lengths and the results plotted in a curve similar to Fig. 8. In a similar manner the spectral sensitivities for a uniform distribution of radiant flux might have been determined for each of the other emulsions; however, for practical reasons the method employed was as follows:

By using a moderately wide slit on the quartz spectrograph a series of spectrograms of a quartz mercury arc was made upon

FIG. 5.

	Exposure
C-2 Daylight Glass	8 Minutes
Soda-Lime "	8 "
Quartz Mercury Only	40 Seconds
Blue-Green (Copper) Glass	8 Minutes
Boro-Silicate "	8 "
Soda-Lead "	8 "
Soda-Lime "	8 "
C-2 Daylight "	8 "
C-3 Photographic "	8 "
Blue-Green (Copper) "	4 "
Boro-Silicate "	4 "
Soda-Lead "	4 "
Soda-Lime "	4 "
C-2 Daylight "	4 "
C-3 Photographic "	4 "

Spectrograms of radiation from quartz mercury arc through various lamp-bulb glasses.

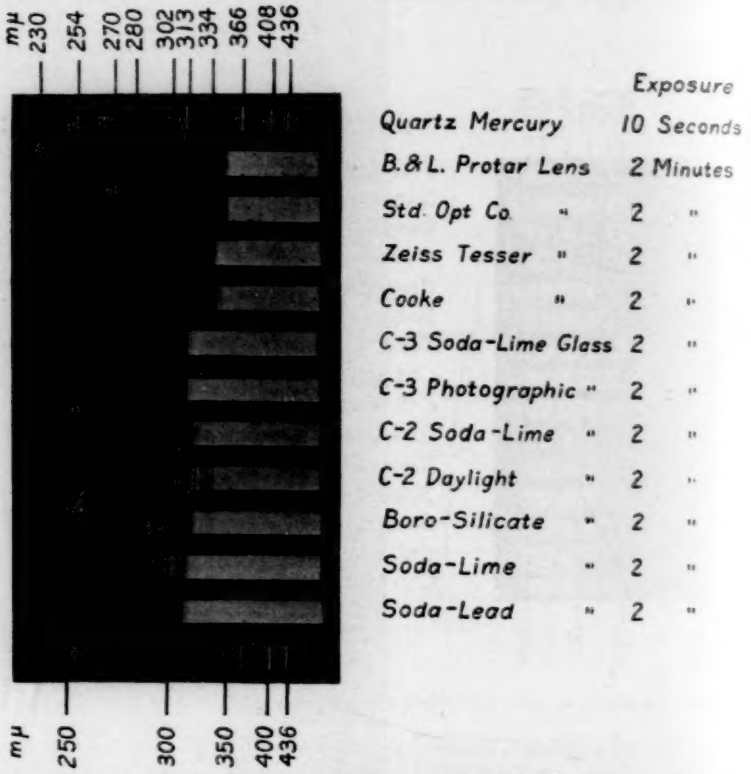
each type of emulsion under identical conditions. From exposure-density curves, plotted for each line of the mercury spectrum, inertias were obtained for each type of emulsion and from them the sensitivity of each type of emulsion was found in terms of the Seed's 23 emulsion. Then to obtain the relative spectral sensitivities of each emulsion, *i.e.*, for a uniform distribution of radiant flux, these relative sensitivities were multiplied by the relative spectral-sensivities of the Seed's 23 emulsion obtained for the continuous spectrum of uniform flux density. The results

for all four types of emulsions were plotted in curves similar to those in Fig. 8.

Relative spectral-sensitivity curves having been obtained for each type of emulsion, it was necessary to find their absolute sensitivities, which was done as follows:

From data in Table I, Part III, the pseudo-actinicity of the

FIG. 6.

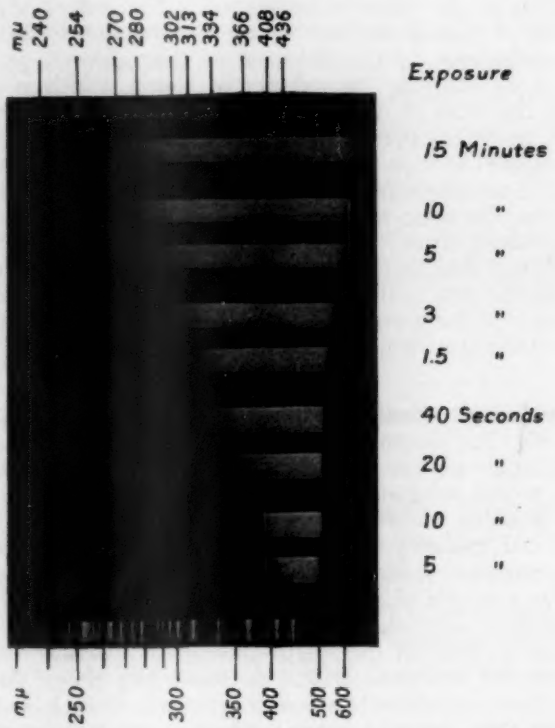

mμ 230 254 270 280 302 313 334 366 408 436
Exposure
Quartz Mercury 10 Seconds
B.&L. Protar Lens 2 Minutes
Std. Opt Co. " 2 "
Zeiss Tesser " 2 "
Cooke " 2 "
C-3 Soda-Lime Glass 2 "
C-3 Photographic " 2 "
C-2 Soda-Lime " 2 "
C-2 Daylight " 2 "
Boro-Silicate " 2 "
Soda-Lime " 2 "
Soda-Lead " 2 "
mμ 250 300 350 400 436

Spectrograms of radiation from bare iron arc through various lamp-bulb glasses, and through four types of photographic lenses.

radiations from tungsten at 3060° K. through quartz is 8.55 for a Seed's 23 emulsion. From Fig. 15, Part VI, the luminous efficiency of this radiation is 23.9 lumens per watt; and therefore the total number of ergs of this radiation per square centimetre of emulsion is 4.9. Assuming the Seed's 23 emulsion to be of practically uniform sensitivity for all wave-lengths between 300 mμ and

450 mμ and observing that these short-wave radiations produce 61 per cent. of the total blackening of the emulsion, we have found the total equivalent energy of these short-wave radiations by computing their proportion of the whole by use of equation (13), Part VI. Thus we find the inertia in ergs per square centimetre of radiation of wave-length 436 mμ for a Seed's 23 emulsion to

FIG. 7.



Spectrograms of radiation from tungsten at 3000° K. through quartz, with various lengths of exposure.

be .075 and the corresponding sensitivity S to be 1/.075 or 13.3. Similarly the inertia in ergs per square centimetre of a Seed's 26 emulsion for radiation of wave-length of 436 mμ was computed to be .0312 and the corresponding sensitivity to be 1/.0312 or 32.

Spectral sensitivity curves for all four types of emulsions are shown in Fig. 8, in which the ordinates are true sensitivities or the reciprocal of inertias in ergs per square centimetre.

(To be concluded.)

Determination of the Ratio of the Two Specific Heats of Carbon Dioxide. BRUNO TORNAU. (*Zeit. f. Physik.*, Dec. 9, 1922.)—In gases with several atoms in each molecule there exists a definite relation between the energy of translation of the molecule and its internal energy, which is permanent as long as a state of equilibrium is maintained. Upon this relation depends further the ratio of the specific heat at constant pressure to that at constant volume. The assumption has been tacitly made that the same ratio between the energies is established no matter how short a time be allowed for the redistribution of the energies concerned. The author sets himself the problem of finding whether he can discover any variation of the ratio in consequence of the shortness of time allowed, and he gets his solution by studying the velocity of sound, which is known to depend on the ratio of the two specific heats, as dependent on the number of vibrations per second of the tuning fork source. Carbon dioxide was used because it is an imperfect gas and might be expected to manifest a departure from uniformity. He found that the velocity of sound was the same within the limits of experimental error with waves originating from forks of 256, 512 and 1024 double vibrations per second, and that the ratio of the specific heats and consequently the ratio of the two quantities of energy were likewise independent of the changes in the pressure of the gas traversed by the sound wave. The ratio of the specific heats came out equal to 1.3165. G. F. S.

On the Longitudinal Elasticity and Poisson's Ratio of India Rubber. G. B. DEODHAR ALLAHABAD. (*Phil. Mag.*, March, 1923.)—Though we are all fairly familiar with some of the elastic properties of this substance it is none the less interesting to have our crude observations confirmed by careful experiments. For example, a piece of old rubber cord was 19.25 cm. long when a weight of 520 grams stretched it and its cross-section had then an area of .3771 sq. cm. For a weight of 5020 grams the length became 49.87 cm. and the cross-section .1536 sq. cm.

"A close scrutiny of the length-tension curve shows that up to a point where the stretched length is about 5/4 times the original length, a linear relation between length and tension holds good. Then, after that, there is a bend till the stretched length attains about twice the original value; after that, up to the breaking point, a linear relation holds good again. . . . The second linear relation is more conspicuous than the first one as its range is larger." Young's Modulus is far from being a constant, increasing with added weights until it becomes as much as four times its original value. For the same experimental range Poisson's ratio sinks from .87 to .38. There is so much variation in the elastic properties of india rubber that it is quite remarkable to find that the ratio of the square of the length to Young's Modulus is nearly a constant over the two ranges where the linear relations above mentioned hold. G. F. S.

THE COLORING AND THERMOPHOSPHORESCENCE PRODUCED IN TRANSPARENT MINERALS AND GEMS BY RADIUM RADIATION.*

BY

S. C. LIND, Ph.D., and D. C. BARDWELL.

IN an earlier paper [1] one of us reported some observations on the coloring, decolorization and thermophosphorescent effects resulting from the radiation of glass by radium rays. Similar experiments, extended to transparent minerals and gems, are described in the present paper.

The following terminology has been adopted:

	No Radiative Stimulation.	Radiative Stimulation	
		Without After-effect.	Causing After-effect.
No Thermal Stimulation	*Luminescence*	*Fluorescence*	*Phosphorescence*
With Thermal Stimulation	*Thermoluminescence*	*Thermofluorescence*	*Thermophosphorescence*

By thermal stimulation in general is meant that produced by raising the temperature above the normal, but this is not to be understood as precluding the possibility that a phosphorescent effect at ordinary temperature may vanish at a lower one, showing it to have been really thermal in nature. By radiative stimulation is meant that by any radiation (including corpuscular) except that form included under heat radiation. Under this usage the term *thermoluminescence*, previously used, becomes thermophosphorescence. A study of luminescence and thermoluminescence (new definition) is not included in the present paper.

* Communicated by Dr. R. B. Moore, Chief Chemist, U. S. Bureau of Mines, and Associate Editor of this JOURNAL. Communication from the Rare and Precious Metals Experiment Station, U. S. Bureau of Mines, in Coöperation with the University of Nevada. Published by permission of the Director, U. S. Bureau of Mines.

[1] S. C. Lind, *Jour. Phys. Chem.*, **24**, 437–43 (1920).

This subject has already been studied by various investigators.[2] The results recorded here are in the main confirmatory of previous observations, though complete agreement is not to be expected owing to the variations encountered from specimen to specimen of the same material. It therefore seems desirable to report all the results, although many of them duplicate those of previous investigations, in order to be able to consider them together with the other effects described, many of which are new. An additional reason for the joint consideration of decolorization and thermophosphorescence is found in the possible theoretical connection between the two which will be more fully discussed later in the paper.

The diamond is so unique in its behavior under radium radiation that it will be separately considered in a subsequent communication. In all cases, except the diamond, coloring is produced by the penetrating (beta and gamma) radiation received through a glass wall of ordinary thickness (½ to 1 mm.). The diamond, however, did not change color under penetrating radiation, even though prolonged and intense, but responded in every case to direct alpha radiation, either from emanation or by direct exposure to radium salts.

Fluorescent effects are caused in some minerals (kunzite, "active" calcite, willemite, etc.) both by alpha and by penetrating radiation, but in most minerals alpha radiation is the only one producing phosphorescence, while many other minerals do not fluoresce even under its stimulus.

In the following, where radiation is reported in terms of *mgs. of Ra*, we refer to the penetrating radiation from high-grade salt (chloride or bromide), 70 to 100 per cent. pure, placed immediately in contact with the mineral and separated only by the glass wall of the container. Where *emanation* is specified, the mineral has been sealed in a glass tube containing radium emanation furnishing alpha, beta and gamma rays. As in the case of glass, the same color is produced in a given specimen (except diamond),

[2] A. Miethe, *Ann. d. Phys.*, **19**, 633 (1906). C. Doelter, "Das Radium und die Farben," Steinkopf, Dresden, 1910, also "Die Farben der Mineralien, Insbesondere der Edelsteine," Vieweg und Sohn, Braunschweig, 1915. E. Newberry and H. Lupton, *Memoirs and Proc. Manchester Lit. and Phil. Soc.*, **62**, No. 10 (1918). St. Meyer and K. Przibram, *Sitzb. Akad. Wiss. Wien*, **123**, IIa, 653–63 (1914). K. Przibram, *ibid.*, **130**, IIa, 265–70 (1921). St. Meyer and E. v. Schweidler, "Radioaktivität," Teubner, Leipzig-Berlin (1916), pp. 191–7; Lit. refs., p. 198. A. Dauvillier, *Comp. Rend.*, **171**, pp. 627–9 (1920).

either by emanation or by penetrating rays, more rapidly by the former.

Thermophosphorescence was observed visually by placing freshly radiated specimens in an electrically heated muffle, inspecting in the dark with well-rested eye the light emitted upon gradually raising the temperature. In the case of direct radiation by means of emanation the observations were not made until at least four hours had elapsed after removal of the specimens from the emanation in order to allow the active deposit to decay, thus avoiding any direct fluorescent effects.

The observations for individual minerals were as follows:

Rock salt is readily colored to an amber yellow by 250 mgs. Ra in one to two days. It is easily restored to colorless by heating to 300° C. without thermophosphorescence, or by exposure to direct sunlight for one to two hours. Decolorization by diffused light is much slower. The cycle can be indefinitely repeated from color to colorless, either by heat or light, and back to color by radiation.

Through the kindness of Drs. A. W. Hull and W. P. Davey of the General Electric Company, X-ray diffraction spectrographs by the powder method [3] were made both of the colorless and of radium-colored crystals. As will be seen (Fig. 1) the two lattice patterns are identical, showing that no change is produced in the colored specimen which can be detected by the X-ray spectro-

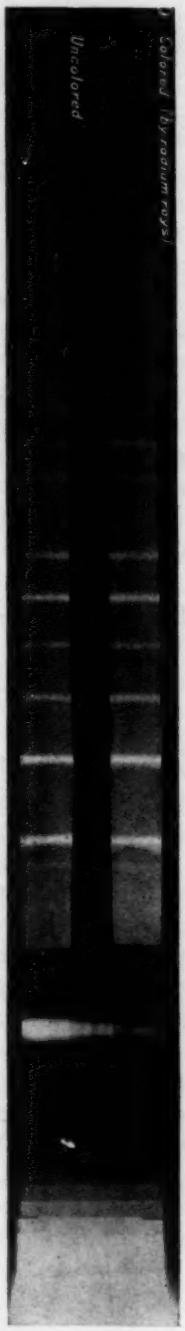


FIG. 1.

Comparison of X-ray spectra of colored (by radiation) and natural colorless rock salt.

[3] A. W. Hull, *Phys. Rev.*, 10, 661 (1917); 17, 571 (1921); *Proc. Am. Inst. Elec. Engs.*, 38, 1171 (1919); *J. Am. Chem. Soc.*, 41, 1168 (1919).

graphic method. The question of the displacement of *electrons* is discussed later in the paper.

Fluorspar.—Different varieties, purple, green, rose, and colorless, are readily colored in one to three days by 250 mgs. Ra to various shades of blue and greenish-blue, which color is easily removed by sunlight or by heat. Thermophosphorescence is striking (next in intensity to kunzite) and like kunzite begins at a low temperature. At 70° C. the light is blue, changing to greenish-blue at 125° and remaining unchanged at 150°. At about 180° the crystals decrepitate and the color produced by radium is discharged. A specimen of rose-colored fluorspar could be colored bluish-green repeatedly under radiation and the rose color repeatedly restored either by heating or by light. On the contrary, the purple variety became white at the decrepitating temperature and could not again be colored by further radiation. These observations appear to support the organic coloring theory for the purple varieties, but not for the rose colored.

Kunzite.—Different specimens of California kunzite behave with remarkable uniformity both as regards coloring and thermophosphorescence. Under radiation from 50 to 100 mgs. Ra, the original lilac color vanishes and the crystal after twenty-four hours' radiation is almost white, which may be due to color compensation by the green color being produced. In two days the green color is well developed and reaches a maximum about the third day, approaching an emerald green, though somewhat lighter. The color is readily restored to lilac, either by light or by heat, and by ultra-violet light in remarkably short time. The cycle can be repeated indefinitely, apparently without fatigue. Fluorescence under penetrating or alpha radiation is of a characteristic orange-yellow or salmon-yellow, and less brilliant phosphorescence has been observed for more than a month after cessation of radiation. In the long duration of phosphorescence it resembles calcite as well as in the color of the phosphorescent light. In thermophosphorescence kunzite exceeds all of the other minerals hitherto examined. Well below 100° C. the intensity of light becomes much enhanced, at 125° it becomes a bright yellow, and at 200° a watch dial is well illuminated by the light from a small crystal. If raised rapidly to 250°, the light is very brilliant, but becomes exhausted rapidly at this temperature, and drops to a much lower intensity with a reddish hue. Apparently

simultaneously with exhaustion of most of the light, the original lilac color is restored. In fluorescence kunzite responds immediately to either penetrating or alpha rays from quite small quantities of radium and no marked change in fluorescence is observed as the coloring progresses.

From the standpoint of coloring, fluorescence and phosphorescence, kunzite is the most interesting of all minerals, and together with fluorspar and calcite forms a distinct class.

Calcite.—Different varieties of calcite showed the greatest differences in the properties of coloring, fluorescence, and of thermophosphorescence, which vary from complete absence to presence in marked degree. Through the kindness of Prof. William P. Headden of the Colorado Agriculture College, we have had an opportunity of observing some of the effects in special specimens of calcite which he had collected. Some of the varieties were colored yellow by 200 mgs. of Ra in the course of one to two months or by 150 millicuries of emanation in one to two weeks, when contained in rather large tubes. The fluorescence of certain samples is marked under the influence either of alpha or penetrating radiation. The color of fluorescence is a reddish orange and phosphorescence is very persistent at ordinary temperature. Professor Headden will describe his results for calcites in the *American Journal of Science,* to which reference should be had for a full consideration of the subject. The varying behavior of calcite is in marked contrast to the uniformity of kunzite as they came under our observation. The varieties of calcite which are active are quite comparable, however, with kunzite both in fluorescence and phosphorescence produced by radium radiation.

Sapphire.—Experiments have been carried out with 25 or 30 specimens of different colors and from various localities, including some synthetic ones. All specimens were uniform in exhibiting no fluorescence, either to penetrating or to alpha radiation. Thermophosphorescence was not observed in natural crystals, but was exhibited faintly by both white and pink synthetic crystals. The thermophosphorescence was characterized by the relatively high temperature at which it appeared (above 150° C.) and at which it persisted (350° for a pink synthetic crystal). At 350° it was more brilliant than kunzite which had passed its maximum at a lower temperature and had dropped to a much fainter intensity. The thermophosphorescence of syn-

thetic pink sapphire was red or orange-red, of synthetic white was yellow, which became paler with increasing temperature. Not a sufficiently large number of natural crystals was examined for thermophosphorescence to be sure that its absence is characteristic.

Change of color under radiation is general, but not universal. Colorless crystals either natural or synthetic are usually changed to golden or canary yellow in two to three days by the radiation from 200 mgs. Ra. Pink crystals either natural or synthetic were easily changed to a burnt orange color, probably corresponding to the addition of yellow to the original pink. Blue crystals change to a grayish or brownish-green, without beauty or brilliancy, but the original color can be restored either by light or heat. Light yellow is usually deepened to a canary yellow, but may take green shades instead, which latter may also result in some cases from colorless specimens. In no case observed was the color produced light-permanent, resembling in this respect rock salt, kunzite, and fluorspar.

Ruby.—The color changes in ruby are not marked. Light-colored natural ruby was not changed by radiation. Synthetic ruby was slightly darkened. Neither natural nor synthetic ruby showed any fluorescence under penetrating radiation, but showed a faint deep red fluorescence in emanation. Synthetic ruby showed a faint dark red thermophosphorescence at 150° C.

Emerald.—Neither natural nor synthetic emerald showed fluorescence under penetrating or alpha radiation; nor was change of color produced in any case. Synthetic emerald which had been exposed to 150 m.c. of emanation for ten days showed a faint green thermophosphorescence at 200° C.

Topaz.—Several different specimens of colorless topaz responded very uniformly to the penetrating rays from 200 mgs. Ra, though more slowly than rock salt, sapphire, and kunzite. In about a month a brownish amber color was produced which was uniform in all the specimens examined. Smoky topaz deepened in its own shade. The colors produced in topaz are apparently light-permanent. Neither fluorescence nor thermophosphorescence was observed.

Garnet.—Three specimens of deep red garnet acted uniformly in undergoing a reduction in color by the penetrating rays from 200 mgs. Ra, the color changing from deep red to violet, or

purple. The color change produced is apparently light-permanent. No fluorescence nor thermophosphorescence was observed.

Quartz.—A fairly large number of specimens of different varieties of quartz was examined. In most cases the smoky color, characteristic of some varieties of natural quartz, is produced by radiation either from an initial colorless or by deepening a light smoky color or by changing the amethystine or rose color to smoky. A few failures to produce any color in colorless quartz by 200 mgs. Ra in one month were encountered.

In some cases radiation of light amethyst deepens the amethystine color, in other cases it changes to the smoky color. Continued failure to produce amethystine color in colorless quartz suggested the following test: A crystal of amethystine quartz was decolorized by heating in air to a dull red. After cooling, it was exposed to the penetrating radiation from 200 mgs. Ra which gradually restored the amethystine color, and after several months carried it to a much deeper amethystine shade than the original. While quartz is not fluorescent, either under penetrating or alpha radiation, most specimens show a marked thermophosphorescence of bluish-white or bluish-green shade, which is quite persistent and equal in brilliancy to that of fluorspar. Other specimens of milky quartz and amethystine quartz showed no thermophosphorescence following radiation, though both were decolorized under heating.

Glass.—Since the publication of the previous paper on the coloring and thermophosphorescence of glass, some additional results have been obtained which will be described here.

At the suggestion of Professor Bancroft and Mr. Jerome Alexander, of the National Research Council, a rather detailed study was made of three slides of different thicknesses of decolorized gold ruby glass[4] to see if restoration of ruby color could be observed and followed by the ultra-microscope, in an attempt to throw some light on the nature of the color and the supposed colloidal coagulating action of the radiation. As in a previous attempt,[5] with much less satisfactory material, no ruby color

[4] The slides used were prepared by the Corning Glass Works through the kindness of Doctor Sullivan, to whom we are greatly indebted. They were about the size of microscope slides, ½, 1, and 5 mm., respectively, in thickness, were absolutely colorless, and splendidly prepared.

[5] *Loc. cit.*, p. 441.

was produced. This time a brownish or amber yellow resulted (in conformity with Doelter's result) instead of the violet previously obtained. This seems to show conclusively that radium radiation does not develop the ruby color in decolorized gold ruby glass, but brings out the usual color characteristic of the glass exposed to the radium rays—violet, yellow, or brown, depending on some other property of the glass. Mr. Alexander's ultramicroscopic examination of the colored slides failed to disclose colloidal particles, although the radiations had been continued for several weeks until the amber color had become very marked in the two thick slides.

Specimens of special glass (paste), cut to resemble a diamond, gradually colored an amber-brown under penetrating radiation from 200 mgs. Ra. On exposure to diffused light it changed back to colorless almost as rapidly as rock salt, which is the first instance of the rapid bleaching of radium-colored glass by light that has come to our attention.

A piece of glass which had been colored violet by radium about six years ago failed to show any thermophosphorescence up to 300° C. This appears to confirm the theory advanced in the previous paper that the condition produced in glass by radiation which causes thermophosphorescence, slowly reverses itself even at ordinary temperature without affecting the color.

Obsidian.—The colorless variety usually is colored smoky by penetrating radiation, but occasionally fails to become colored. The light smoky variety deepens to black in the course of one to two months under penetrating radiation from 200 mgs. Ra. It resembles quartz in its behavior regarding coloring and was not tested for thermophosphorescence.

Tourmaline.—Two specimens of tourmaline, one pink and one green, showed no change in color under penetrating radiation. The green tourmaline failed to fluoresce or to change color in ten days' exposure to an initial quantity of 150 millicuries of emanation, and later failed to show any thermophosphorescence up to 300° C. The pink specimen was examined only with respect to coloring by penetrating radiation.

Diamond.[6]—More than thirty specimens of cut diamonds, supposed to represent the principal diamond fields of the world, varying in size from a fraction of a carat to ten carats and in

[6] For fuller details, see paper by the same authors which will appear in a later issue of this JOURNAL.

color from colorless to yellow and caramel brown, were examined. Fluorescence under penetrating radiation from a very thin tube containing 60 mgs. Ra could not be detected. Fluorescent response to alpha radiation in the emanation tubes was universal and very sensitive. The color of the fluorescent light in emanation varied for different specimens from green to bluish-green to greenish-blue to blue without any regularity with reference to the color of the diamond itself. For the same specimen the color of fluorescence varied somewhat with conditions as to intensity of radiation and gas pressure in the emanation tube (perhaps the latter only as effecting the former). Fluorescence was also observed near a thin alpha-ray bulb containing emanation.

Prolonged exposure (one month) to *penetrating rays* from 250 mgs. Ra failed to produce any change in color in five yellow Cape diamonds of four to ten carats. But prolonged exposure (45 to 75 days) to *alpha radiation,* either directly in 10 to 50 per cent. $RaCl_2$ salt or in emanation, produced universally a green color, which deepened with time (or with intensity of radiation) through grass green to a dark sage green. These results confirm that of Sir William Crookes [7] and met with no exception in all the more than thirty specimens treated. Colorless and yellow diamonds seem to take equally perfect green. Brown diamonds were off shade toward olive probably due to superimposed brown. The color is apparently light-permanent but can be discharged by heating to 450° C. for about an hour and in a shorter time at higher temperatures, or more slowly at lower ones. By interrupting the heating any intermediate shade of green can be obtained. The original color is finally restored by continued heating. The puzzling question as to the depth of the penetration of the colored layer, and the appearance in some specimens of "carbon spots" will be considered in the following paper devoted exclusively to the diamond.

Chrysoprase, opal and *other opaque minerals* showed no color change. This seemed to be a general characteristic of the opaque minerals. Upon heating chrysoprase after exposure to emanation, no light effects were observed, but a surface discoloration was produced which destroyed the natural lustre of the cut stone.

Aquamarine (light green), *zircon* (almost colorless), *peridote*

[7] Sir Wm. Crookes, *Phil. Tr. Roy. Soc.*, **214A**, 433–45 (1905); *Sci. American*, Supplement No. 2270 (July 5, 1919).

(light green), and *moss agate* exhibited neither color change nor luminous phenomena. Aquamarine was exposed to penetrating radiation from 210 mgs. Ra for almost two years without changing hue in the slightest.

DISCUSSION OF RESULTS AND THEORY.

The foregoing observations make no pretense to completeness, but are rather intended to show the complexity of the phenomena exhibited by the various transparent minerals and gems with respect to coloring and the emission of fluorescent and phosphorescent light, and to illustrate the difficulties that are encountered in attempting to propose a satisfactory theory. One is confronted with a most confusing complexity of relations and almost every possible combination is met. On the one hand, we have minerals like aquamarine and peridote which show a negative behavior throughout toward the radium radiations, being neither colored nor excited to any light emissions. Again, at the other extreme, we have a few minerals like kunzite and fluorspar which always exhibit in marked degree the phenomena under consideration. Among different specimens of the same mineral, we also have all extremes of behavior from complete regularity to almost complete variability. Such variable behavior has generally been regarded and, in the opinion of the writers, is properly regarded as pointing to the presence in certain minerals of *impurities* which are mainly responsible for their behavior during and following radiation. In those minerals, on the other hand, where no irregularity of behavior is observed, one is forced to the conclusion that the phenomena exhibited are due to properties inherent in the mineral itself.

That the presence of impurities, sometimes in minute quantities, plays a rôle in a variety of phenomena connected with coloring and light emission has been known for some time. It has been recognized in the case of phosphorescent alkaline earth sulphides, in the fluorescent-phosphorescent zinc sulphides, in the natural coloring of minerals, in the color produced in minerals by radiation, in the triboluminescence of natural zincblend (which must contain iron or manganese to show triboluminescence), and in many other related phenomena. It is not the purpose of the present paper to discuss primarily the rôle played by these impurities, though reference will again be made to them. A complete

explanation of their action will probably not be found until much more is known about the exact mechanisms of the various effects.

Several theories have been proposed to explain coloring and the light effects. In all of the most recent ones the influence or concomitance of *electrical* phenomena is recognized. There has been no lack of confirmation of the general truth of such a relation. Röntgen [8] recently published a very exhaustive study of the influence of light and other forms of radiation on the conduction of electricity through crystals, principally sodium chloride.

Lenard [9] has investigated the effect of light on phosphorescent zinc sulphide from the standpoint of photo-electricity. Earlier Meyer and Przibram [10] reported that minerals which had been colored by radium radiation exhibit enhanced photo-electric effects. Przibram [11] has further developed their original theory. There can then be little doubt that the phenomena depend primarily upon electrical effects produced in the minerals by radiation. It is also most natural to suppose that the light effects during subsequent heating are caused by the return of electrons to their original positions. Insofar the present writers can agree with the general theory.

The statement previously made by one of us,[12] based on the behavior of violet-colored glass that: "The mistake has been rather commonly made of supposing that there is a close connection between the discharge of color produced in glass, for instance, and thermophosphorescent effect," appears to have been slightly misunderstood by Przibram.[13] It was not meant to imply that there is *no* connection between the two phenomena. We agree with Przibram that when a mineral exhibits both thermophosphorescence and decolorization by heat, usually the two phenomena are *apparently* coincident. We are inclined to believe that a more careful examination of this coincidence should be made before the statement can be made positively. The case of glass does appear to be exceptional, but the occurrence of even *one*

[8] W. C. Röntgen, *Ann. d. Phys.* [4] **64**, 1–195 (1921).

[9] P. Lenard, *Ann. d. Phys.* [4] **38**, 553–73 (1922).

[10] St. Meyer and K. Przibram, *Sitzb. Akad. Wiss. Wien*, **123**, IIa, 653–63 (1914).

[11] *Ibid.*, **130**, IIa, 265–70 (1921).

[12] Lind, *Jour. Phys. Chem.*, **24**, 442 (1920); also "Chemical Effects of Alpha Particles and Electrons," p. 52.

[13] *Loc. cit.*, p. 265.

such marked exception as that of glass, where the temperature of maximum thermophosphorescence and of decolorization differ by 200 to 300° C., should serve to make one very cautious in making any generality requiring that decolorization and thermophosphorescence coincide, and have an absolutely identical cause. Moreover, as shown in the present paper, and as is generally known, we have numerous cases of minerals in which one or the other of these two phenomena (coloring or thermophosphorescence) is lacking. For example, rock salt and sapphire, which are readily colored, show no visible light at the temperature of decolorization nor at any other temperature below incandescence. On the other hand, certain varieties of calcite, which show marked thermophosphorescence following radiation, are not colored by radiation at all. A more careful study of other minerals may disclose that even where both phenomena are exhibited they are not always coincident. It should be mentioned, however, that such coincidence does not appear to be essential to the theory of Meyer and Przibram any more than it is to the one which will be advanced in the present paper.

The principal point of departure of the different theories is in regard to what produces the color. In the theory of Meyer and Przibram the assumption was made that the primary effect of radiation is to furnish electrons which then neutralize positive metallic ions, giving neutral atoms of the metals. Coagulation (Ausscheidung) into colloidal particles then takes place which are responsible for the color. Meyer and Przibram support this theory by the similarity of colors produced in a series of synthetic alkali and alkaline earth borates to the colors found by Svedberg [14] for the organic sols of the corresponding bases. Decolorization and accompanying thermophosphorescence are then caused merely by the reversal of this process under the stimulation of heat. The electrons liberated by the heat return to their original positions with the emisssion of light; the colloidal particles disintegrate, and the original color is restored. While the theory is a very elegant one, the present experiments appear to lend it little support. The efforts to reproduce by radiation the ruby color of gold-ruby glass which had been decolorized by heat, not only produced no ruby color, but produced no particles which could be recognized as colloidal in the ultra-microscope, although the usual colors of glass

[14] T. Svedberg, "Die Methoden zur Herstellung Kolloider Lösungen," Dresden (1909), pp. 481 and 486.

(violet in one case and yellow in another) were produced. This seems to show that the colors produced in glass, and certainly in those minerals which are even more easily colored, are more readily brought about than is colloidal separation and cannot be attributed to the latter. In fact, the great ease with which some minerals are colored and the corresponding ease with which they are decolorized (even by diffused light of low intensity), leads us to look with disfavor on any theory involving the transport of masses of atomic size (or larger) through a solid medium.

The theory advanced by Newberry and Lupton [15] is simpler than that of Meyer and Przibram. It involves only the assumption of primary ionization into a positive and a negative ion, both of atomic dimensions, one of which is capable of producing color and both of which remain separated by minute distances. Under stimulation of heat the ions recombine (with the emission of light) as in ordinary chemical reaction. While the objections to this theory are less formidable, nevertheless it appears to have been conceived more in conformity with the principles of ionization in electrolytic solutions and without any special reference to electronics or to crystal structure as revealed by the space lattice.

The following appeals to us as a simpler and more general theory.[16] Certain groups of *electrons* are displaced by radiation from their normal positions and take up new metastable positions among the atoms. No displacement (or only secondary displacement) of the atom is involved. No change in the crystal lattice as revealed by X-rays would be expected nor would there be any production of colloidal particles. One or more groups of electrons may be involved. By *group* is meant a number of electrons all having uniform positions in the original atoms from which they are displaced and taking after displacement uniform new positions among the other atoms.

In cases where two or more groups are involved, the return of one group to the original position may cause thermophosphorescent effects, the return of a different group may cause decolorization. This does not preclude the possibility that a single group may bring about both phenomena, thus rendering them absolutely

[15] *Loc. cit.*

[16] The possibility of a theory based on a change in the mode of electronic "binding" (Bindungweise) was mentioned in the earliest paper of Meyer and Przibram (*Sitzb. Akad. Wiss. Wien*, **121**, IIa, 1416 (1912)), but was not further elaborated nor mentioned in their subsequent papers.

coincident. On the other hand, the possibility is evident that the two may be entirely independent, each having a different energy index or either one may be entirely lacking, as we have shown to be the case for certain minerals.

According to this theory the color might still be due to the positive ions. It appears to us, however, more probable that the color is due to the vibration of the electrons in their abnormal positions. G. N. Lewis [17] has assumed the production of color in organic compounds by the vibration of electrons partially relieved of their constraints by a change in the surrounding electrostatic field so that they vibrate at a lower frequency which may fall in the visible region. He has shown that, owing to their small mass, electrons are more readily influenced as resonators than are atoms or ions. Our assumption is then that these electrons are removed by radiation to abnormal positions in which their constraints are lessened so that they vibrate with a frequency which may, and frequently does, fall in the visible region. Since the crystal is transparent the color complementary to the one absorbed by the electronic vibration is transmitted. In the metastable positions, under less constraint, the electrons are also freer to take part in electrical conduction and in photo-electric emission under radiative stimulus, and can also return to their normal positions under this stimulation or by that of heat.

Color-saturation would then be reached under continued radiation when the number of electrons returning to normal positions just equals the number being displaced. Upon cessation of radiation the electrons in abnormal positions may either remain indefinitely in the metastable position or may return gradually to their normal positions. The latter action will be brought about more rapidly by the stimulation of heat or some form of radiation of sufficient intensity to displace electrons from their abnormal positions without causing others to be driven from normal positions. One set of electrons may slowly revert, while another set remains indefinitely displaced. This is apparently the case in violet-colored glass where the power to thermophosphoresce gradually disappears even at ordinary temperature while the color persists undiminished. At about 200 to 300° C. the former action becomes very rapid and is complete in one-half to one hour, while the color is not discharged below 450 to 500°.

[17] G. N. Lewis, *Chem. Met. Eng.*, **24**, 871–5 (1921).

The influence of impurities, in the light of this theory, may be one or both of the following: (1) To loosen electrons so that they are more readily displaced. Again this effect may be due (*a*) to an effect exerted only on the electrons of the original atoms, or (*b*) by the formation of complexes from which the electrons are more readily displaced than from normal atoms. (2) The influence exerted by the impurities may be exerted on the electrons after liberation, in holding them more firmly in the abnormal positions, or both (1) and (2) may act jointly in some cases. The presence of an impurity may not be essential in all substances to the electronic displacements under consideration.

Although this theory may be more comprehensible when considered in the light of the atomic structure in a crystal lattice, a crystalline or lattice structure is evidently not essential, as illustrated by the behavior of glass. It is evident that a crystal structure is not regarded by Lewis as essential to his electronic theory of color, since he extended it to the color produced by the reaction $N_2O_4 - 2NO_2$.

It is also evident that one would not expect the phenomena under discussion to be exhibited by any but transparent minerals. It is shown in the present paper that opaque minerals do not show any color changes under radium radiation. It may also be pointed out that those minerals which have intrinsic color (Doelter's "Eigenfarbige") are usually opaque minerals, while those which have no intrinsic color, which show variety of color in nature and are subject to coloring by radiation, are all transparent minerals.

We can find in the present results very little support for the theory that colored minerals in nature have been colored by the action of the earth's radioactivity. If this were the case for diamonds, for example, we should expect to find in nature many *green diamonds,* since this has been shown to be the commonest (and in our experiments the only) color produced by radium radiation; but actually *green* is a very rare color in natural diamonds. (See paper on the diamond which will appear in a later issue of this JOURNAL.) Furthermore, the artificial colors, even when similar to the natural ones, appear to be much less permanent with respect to heat and often with respect to light.

On the basis of the present theory the actual proportion of color-producing electrons to the total number of atoms in a given slightly colored mineral must be quite small. It is calculated from

ionization by penetrating radiation that the fraction in rock salt just noticeably colored is of the order 10^{-5}. Accordingly the quantity of energy necessary to produce (and even more so to discharge) color is surprisingly small in some cases. In general, it may be stated that the colors which are most easily produced are also most easily discharged and *vice versa*.

While it may be objected that the theory here proposed is not very definite and has not been quantitatively supported, it appears to us that it is capable not only of explaining the phenomena under consideration, but also has the necessary elasticity to fit the various other phenomena which are encountered and which must be explained. A more quantitative support must await a more intimate knowledge of atomic structure and of the properties of electrons and ions within that structure.

It is a pleasure to express our indebtedness for valuable assistance and suggestions and for the loan or gift of experimental material to: Prof. W. D. Bancroft and Mr. Jerome Alexander, of the National Research Council; to Doctors Hull and Davey, of the General Electric Company; to Professors Jones and Lincoln, of the University of Nevada; to Professor Headden, of the Colorado Agriculture College; to Mr. E. F. Holden, of the University of Michigan; to Mr. J. B. E. Bell, of Reno; to Mr. R. G. Monroe, of New York, and to the Corning Glass Company, of Corning, New York, and to the American Gem Mining Syndicate, of St. Louis.

The Effect of Long Grinding on Quartz. R. C. RAY. (*Proc. Roy. Soc.*, A 718.)—"It has been shown from determinations of the heats of solution that when silver sand is subjected to grinding for a long time in a mechanically operated agate mortar, it partially loses its crystalline structure and is converted into the vitreous state." As there is a considerable difference between the densities of quartz and silicon glass it seemed worth while to see whether grinding affects density. Unground silver sand had a density of 2.638 gr. per cu. cm.; after grinding for fifteen hours it sank to 2.528, while silicon glass gave the value 2.208. From the amount of the change it appears that 25.7 per cent. of the sand was converted into the vitreous state, while from the change in the heats of solution the corresponding percentage was 31.2.

Other investigators have found that grinding diminishes the density of crystalline lead oxide, but fails to produce such a change in the amorphous oxide. G. F. S.

ON THE PHOTOGRAPHIC INTENSITY OF FLASHLIGHT MATERIALS.*

BY

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PHOTOGRAPHIC literature contains an abundance of information relative to certain scientific phases of flashlight photography. The major portion of this literature deals with the chemical content of the flash materials with descriptions of apparatus for the discharge of such materials. It is the purpose of this paper to present information of another nature, that of the photographic intensity of flash materials.

A problem of this type necessarily involves considerable experimental data, and due to the great variety of flash materials available two were selected whose use is widespread, while a third was included as a possible means of corroborating the evidence of one of the others. In a photographic problem the choice of photographic materials is highly important, especially so when the material used is the medium by which intensity values are to be determined.

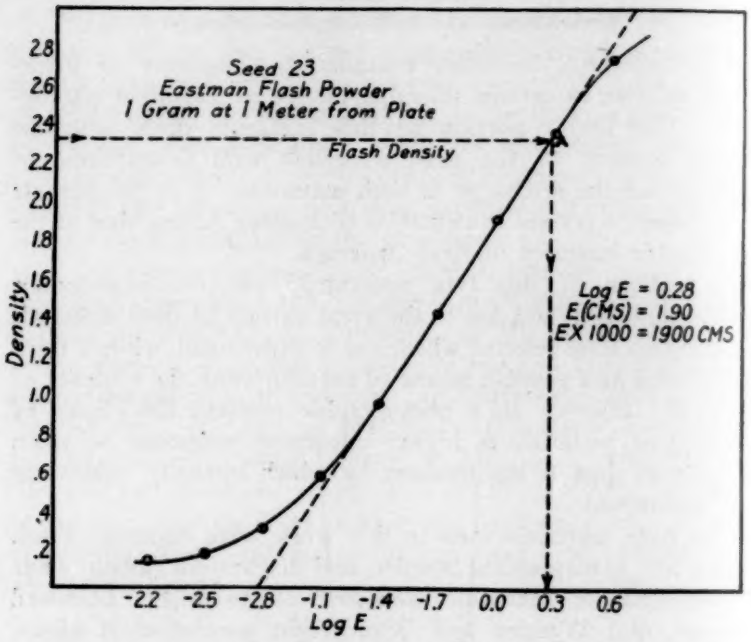
The flash materials used in this work were Eastman Flash Powder No. 3, magnesium powder, and magnesium ribbon, while the photographic materials consisted of Seed 23, Standard orthonon, and Wratten and Wainwright panchromatic plates. Each flash material had its intensity value determined on each of the three photographic materials.

Eastman Flash Powder contains magnesium and other metallic powders and substances which act as accelerators of its combustion. This powder is highly combustible and instantaneous in its action. An apparatus was constructed for the electrical discharge of the powder, each discharge firing one gram. This was accomplished by using nichrome wire between the terminals from the source of electrical supply, the wire being filed thin where it passed into the discharge container.

* Communicated by Dr. C. E. K. Mees, Director of the Laboratory and Associate Editor of this JOURNAL. Published as Communication No. 189 from the Research Laboratory of the Eastman Kodak Company.

The magnesium powder was discharged in an especially designed blow lamp readily obtainable commercially. In this lamp the powder is blown up through an aperture around which is a wick burning alcohol. In this manner it was possible to burn

FIG. 1.



a given weight of powder rather completely. Again each charge contained one gram of powder.

The tests with magnesium ribbon consisted merely in burning one gram of it directly in front of and at a metre's distance from the photographic plate.

The values of photographic intensity were obtained sensitometrically. By means of an instrument described by L. A. Jones,[2] portions of the photographic plate to be tested were exposed and then developed with a flash exposure made with one of the flash materials on another portion of the same plate. It is very important to note at this point that the strips made in the sensitometer

[2] Jones, L. A., "New Non-Intermittent Sensitometer," JOUR. FRANK. INST., March, 1920.

were exposed to an acetylene flame screened with a Wratten No. 79 filter, producing light of daylight quality. Therefore, the values given in this paper are visual candle-powder-seconds of screened acetylene. After completion of the development processes, the characteristic curve of the plate was obtained and on it was marked off the density obtained by the flash exposure. Fig. 1 illustrates the method used. The flash density A is marked off on the curve and projected to the log E axis. The value determined from this point is in metre-candle-seconds, the sensitometric standard exposure notation. This metre-candle-seconds value is numerically equal to the candle-power-seconds value for the light source used, since all exposures were made with the light source at one metre from the photographic plate. The values given in the various tables are therefore in terms of candle-power-seconds. No attempt was made to determine the duration of the flash in the various cases, and it is therefore impossible to separate the candle-power-seconds value into its component parts, time and intensity. Some information relative to the duration of the flash of flashlight materials is contained in a paper by J. I. Crabtree.[3]

Since the intensities of the flash materials were so great and as it was desirable to use one gram (a small, easily measurable, quantity) of each material at one metre from the photographic plate, a piece of carefully selected, visually neutral film with a density of 3.0 (transmission .001) was placed directly in front of the photographic plate during each flash exposure. Although neutral film is not recommended for photographic work due to a lack of photographic neutrality, its use was considered permissible in this case. Tests made without the neutral film, using very small quantities of flash material, showed that the ratio of the results obtained agreed very well with those obtained with the neutral film. The candle-power-seconds values as obtained from the curves were of necessity multiplied by 1000—the factor of the neutral film used. The following tables contain the results obtained in each of the above-stated cases. The values given are the number of visual candle-power-seconds of screened acetylene to which one gram of the various materials is equivalent when evaluated in terms of the photographic material indicated.

[3] Crabtree, J. I., "The Nature and Speed of Flash Powders," *Brit. Jour. Phot.*, January, 1917.

TABLE I.

Candle-Power-Second Values.

Set.	Ordinary Seed 23.	Orthochromatic Standard Ortho.	Panchromatic W. and W. Pan.
Eastman Flash Powder.			
1	1800	1100	1500
2	1800	1250	1300
3	2200	1200	1400
Mean	1900	1200	1400
Ratio	1	.6	.7
Magnesium Powder.			
1	2300	4600	8000
3	2300	4500	7500
Mean	2300	4600	7700
Ratio	1	1.9	3.3
Magnesium Ribbon.			
1	2500	4100	4500
2	2700	4900	5500
3	3400	5400	6600
Mean	2850	4800	5600
Ratio	1	1.7	2.0

The various samples of powder and ribbon used were very carefully weighed and every precaution taken to obtain reliable photographic results. All plates were developed for three minutes in laboratory pyro at 68° F.

Examination of the above results shows that the photographic intensity of the flash powder is greater when determined on ordinary (blue sensitive) materials than when the orthochromatic and panchromatic materials are used. The reverse is true in the case of magnesium powder and magnesium ribbon. It will be noticed also that the values obtained with the pure magnesium are higher than those obtained with flash powder. This is especially true in the case of intensity values evaluated in terms of panchromatic materials. An examination of the spectra of the various materials shows differences due to the presence of metals other than magnesium in the flash powder. The presence of these materials tends to give a larger proportion of radiation in the region of shorter wave-lengths. This may be considered as partly

responsible for the higher relative photographic intensity of this material as determined on ordinary photographic materials. It is also probable that the presence of the accelerating agent causes combustion to take place much more rapidly and at a higher temperature in the case of flash powder than with magnesium powder and magnesium ribbon. This higher temperature also tends to cause a greater portion of the energy to be radiated at the shorter wave-lengths. The flash powder gives therefore a relatively bluer light than the magnesium powder and magnesium ribbon, the result being that the intensity values of the flash powder are higher when measured with ordinary materials. The reverse is the case with magnesium and is due to a preponderance of radiation in the region of longer wave-lengths.

For council and advice in procuring the above data, I am greatly indebted to Mr. L. A. Jones and for experimental assistance my acknowledgments are due Mr. R. F. Fisher, both of this laboratory.

Methyl Red.—This compound is used as an indicator in titrations and for the colorimetric determination of hydrogen ion concentration. It is paradimethylaminoazobenzene-orthocarboxylic acid and forms violet crystals. Its hydrochloride forms steel-blue crystals. Both types of crystals must be dissolved in alcohol to obtain the reagent. A. W. SCHORGER (*Ind. Eng. Chem.*, 1923, xv, 742-743) has studied the synthesis of methyl red, and has prepared its sodium salt as reddish-brown crystals. These crystals are soluble in water; and the resulting solution may be used as a reagent. J. S. H.

Phenol-Chlorine Water Pollution.—According to EDWARD F. KOHMAN, of the Research Laboratory of the National Canners Association (*Ind. Eng. Chem.*, 1923, xv, 518), a medicinal taste in canned peas and pears was shown to be due to the use of river water which had been contaminated by the effluent from a coke plant, and had subsequently been chlorinated for use as a municipal water supply. This type of pollution has recently been noted in the water supply of several American cities. Chlorination imparted the pronounced characteristic taste to water containing 1 part of phenol in 750,000,000. The taste, which is attributed to the formation of a dichlorphenol other than 1, 2, 4 dichlorphenol, or else to the formation of an entirely new compound, was destroyed by an excess of chlorine. The taste was accompanied by a penetrating odor, and developed only at high dilutions. If phenol was present in concentrations greater than 1 part in 50,000,000, only the characteristic phenolic taste of the common chlorphenols was obtained on chlorination. J. S. H.

The Separation of Elements into Isotopes. (*Phys. Rev.*, March, 1923.)—It is no longer a question whether this is possible in the case of mercury. The problem is to do it most quickly and economically. At the meeting of the American Physical Society in the last days of 1922 two papers on this subject were presented from the University of Chicago. R. S. Mulliken reported on a combined evaporation and molecular diffusion method. The mercury is evaporated from a 500-c.c. flask at the rate of 500 c.c. per hour. Of this 80 c.c. diffuses, the remainder condensing and running back into the flask. Since it is the lighter molecules that will evaporate in the greater proportion and that will later diffuse most, the liquid remaining in the flask constantly increases in density. "A spread of 0.1 unit has now been obtained."

W. D. Harkins and S. L. Madorsky at the same meeting described a steel vacuum apparatus that gives a separation of .1 unit in the atomic weight after a run of 180 hours combined with the operation of a smaller still for twenty-five hours. The method is one of evaporation alone. The vapor from the liquid meets a steel ceiling, collects into drops and runs away. This resulting liquid is always .005 unit lighter in atomic weight than the liquid left behind. The operation of the apparatus is automatic after the process has begun except in so far as the addition of mercury and the removal of samples is concerned.

The above experiments came from the University of Chicago. From Columbia University James Kendall reports three additional methods as being tried out for elements other than mercury. "It is possible that in an extreme case such as Li^6 and Li^7 an appreciable difference in the points of fusion of the pure isotopes will exist, and so permit a separation by fractional distillation." Two different methods are being used in an endeavor to separate Cl^{35} from Cl^{37}. According to Nernst's e.m.f. equation the discharge potentials of these should differ by .03 volt. It may, therefore, be possible to separate them by "electrolytic fractionation." Mercury, magnesium and lithium are likewise under examination by this method.

The second chlorine method is this. "An agar-agar gel containing chloride is inserted as a short middle section in a long horizontal tube, being preceded by a gel containing a faster anion (hydroxide ion) and followed by a gel containing a slower anion (acetate ion). When a current is passed, the boundaries between the solutions remain perfectly sharp as the chloride moves slowly toward the anode. New tubes of hydroxide gel are inserted before it reaches its goal, and after it has travelled (say) 100 feet the chloride gel is sectioned and analyzed. If Cl^{35} and Cl^{37} ions possess different mobilities, the front sections should contain only the one isotope, the rear sections only the other. . . . The importance of the application of this method to the separation of the metals of the rare earths, saving the laborious recrystallizations at present necessary, should be noted."

G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

SOME COMPRESSIVE TESTS OF HOLLOW TILE WALLS.[1]

By Herbert L. Whittemore and Bernard D. Hathcock.

[ABSTRACT.]

THE Bureau of Standards has published the results of tests of hollow building tile in its Technologic Paper No. 120.

As the strength is important when built into a wall, similar tile were used in constructing thirty-two walls each 4 feet long, 12 feet high, and either 6, 8, or 12 inches thick.

The work was done in coöperation with committee C-10 on hollow building tile of the American Society for Testing Materials.

The National Fire Proofing Company donated all the tile, which were of such design that all the net area was in bearing when carefully set on end in the wall.

As the strength of these tile was greater than the strength of the average tile used in buildings, the results of this investigation should be used with discrimination.

The mortar was 1 cubic foot of Portland cement, ¼ cubic foot of hydrated lime, and 3 cubic feet of sand dried in an oven.

The walls were laid with great care by an experienced mason, and were of much better workmanship than is usually obtained.

The walls were, with a few exceptions, tested when one month old.

After placing the wall in the testing machine, it was capped with plaster-of-Paris, the upper head brought into contact with the wall, and the cap allowed to set for twelve hours or more.

Compressometers were placed at each corner, and readings taken during the test. Stress curves were drawn to show the behavior of the walls. Strain-gauge readings were also taken both on the tile and across the horizontal joints. Due to the great differences in the modulus of elasticity of the tile and the lack of data on the modulus for the particular tile on which strain-gauge readings were taken, these readings were of little use.

* Communicated by the Director.

[1] Technologic Paper No. 238, price five cents.

The horizontal deflections of the walls were measured at mid height of the walls.

The following conclusions may be drawn from the results of the test:

(*a*) Although the strength of the individual tile in lot A was about twice that for the tile in lot B, the strengths of the walls made from these tile were only slightly greater.

The ultimate strength of the walls made from the A tile averaged about 37 per cent. of the strength of the individual tile, while those made from the B tile averaged about 55 per cent.

(*b*) From the theory of columns, it might be expected that a thick wall, the height being the same, would sustain a greater load than a thin one. These tests, on the contrary, show no effects can be definitely ascribed to "column action," although the slenderness ratio for the 6-inch walls was over 60. This is confirmed by the small deflection of the walls.

(*c*) Apparently, there is no relation between the ultimate strength of a wall and the load at first crack.

(*d*) The walls having the cells of the tile vertical had, on the average, more than twice the strength of those having the cells horizontal. For both these cases, the values of the stress at failure were remarkably constant, being, apparently, independent of the size of the tile. The ultimate stresses computed on the net sectional area were also somewhat greater for the walls having the cells vertical, except for the 6-inch A tile, for which the stresses in the walls having the cells horizontal were slightly greater. Apparently, the advantage of setting the tile with the cells vertical is greater for eccentrically loaded walls than for walls which are axially loaded.

(*e*) In only one case could a direct comparison be made between "broken" and "unbroken" joints. Wall No. 31 with "broken" joints, but in all other respects identical in construction with walls Nos. 25 and 26, which had "unbroken" joints, shows a much higher strength. Conclusions, however, should not be drawn from the results from one specimen. Attention is called to the fact that in these tile the transverse webs were spaced to give full bearing over the end of the tile when the cells were vertical and the joints "broken," as well as when the joints were "unbroken."

(*f*) For the axially loaded walls, the failure was sometimes by crushing at the top and sometimes by vertical cracking through the joints. No consistent difference in strength was found for these two types of failure. Probably the crushing at the top was determined by the plaster cap which was somewhat weaker than the mortar joint.

(*g*) Walls loaded with an eccentricity of 2 inches over one-half the width of the wall had about one-half the strength of similar walls, axially loaded. Apparently, this ratio is independent of the thickness of the wall. The maximum deflection for the eccentrically loaded walls was, on the average, 0.04 inch, undoubtedly a very small value, which was exceeded by six of the axially loaded walls.

(*h*) Failure, in the case of the eccentrically loaded walls, was local. The upper bearing plate rested on two of the webs of each tile in the upper course. The stress in these webs was, therefore, much greater than in the lower courses in which the load was more uniformly distributed.

(*i*) The modulus of elasticity of the walls varied over a wide range, and, apparently, there is no relation between the modulus for the wall and that for the individual tile.

(*j*) Due to the wide variations in the moduli of elasticity of the tile and in the deformation of the joints it seems probable that failure of a tile wall is caused by the unequal distribution of the stresses. Therefore, any means of securing a more uniform stress distribution, such as selection of tile having the same physical properties, and setting them with a uniform thickness of joint would be expected to increase the strength.

Fish Meal as a Feedstuff.—Fish meal is a commercial product obtained by cooking, pressing and drying wholesome undecomposed raw fish material under sanitary conditions. James B. Martin, of the U. S. Bureau of Animal Industry (*Jour. Asso. Official Agri. Chem.*, 1923, vi, 498-501), has studied the lard manufactured from hogs which had received fish meal as part of their ration. The fat of these hogs was identical with that of normal hogs in its physical aspects and ordinary chemical characteristics. However, the fat of the hogs which had received fish meal contained a small amount of the glyceride of clupanodonic acid, the characteristic fatty acid of fish oils. J. S. H.

Nomenclature Rules Adopted by the Nomenclature Committee of the American Chemical Society and That of the London Chemical Society.—1. In naming a compound so as to indicate that oxygen is replaced by sulphur the prefix *thio* and not *sulpho* should be used (sulpho denotes the group SO_3H); thus, HCNS, *thio*cyanic acid; H_3AsS_4, *thio*arsenic acid; $Na_2S_2O_3$, sodium *thio*sulphate; $CS(NH_2)_2$, *thio*urea. The only use of *thio* as a name for sulphur replacing hydrogen is in cases in which the sulphur serves as a link in compounds not suitably named as mercapto derivatives; thus, $H_2NC_6H_4SC_6H_4NH_2$, thiobisaniline. *Hyposulphurous acid*, not hydrosulphurous acid, should be used to designate $H_2S_2O_4$.

2. The word *hydroxide* should be used for a compound with OH and *hydrate* for a compound with H_2O. Thus, barium hydroxide, $Ba(OH)_2$; chlorine hydrate, $Cl_2.10H_2O$.

3. Salts of chloroplatinic acid are *chloroplatinates* (not platinichlorides). Similarly salts of chloroauric acid are to be called *chloroaurates*.

4. Hydroxyl derivatives of hydrocarbons are to be given names ending in *—ol*, as glycer*ol*, resorcin*ol*, pinac*ol* (not pinacone), mannit*ol* (not mannite), pyrocatech*ol* (not pyrocatechin).

5. The names of the groups NH_2, NHR, NR_2, NH or NR should end in *—ido* only when they are substituents in an acid group, otherwise in *—ino;* thus, $MeC(:NH)OEt$, ethyl im*ido*acetate; $NH_2CH_2CH_2CO_2H$, *β*-am*ino*propionic acid (not am*ido*propionic acid); $NHPhCH_2CH_2CO_2H$, *β*-anil*ino*propionic acid; $CH_3C(:NH)CO_2H$, α-iminopropionic acid.

6. Hydroxy—, not oxy—, should be used in designating the hydroxyl group; as *hydrox*yacetic acid, $CH_2(OH)CO_2H$, not *ox*yacetic acid. *Keto*— is to be preferred to *oxy*— to designate oxygen in the group—CO—.

7. The term *ether* is to be used in the usual modern acceptation only and not as an equivalent of *ester*.

8. Salts of organic bases with hydrochloric acid should be called *hydrochlorides* (not hydrochlorates nor chlorhydrates). Similarly hydrobromide and hydriodide should be used.

9. German names ending in *—it* should be translated *—ite* rather than *—it;* as permut*ite*. If it seems desirable to retain the original form of a trade name it should be placed in quotations, as "Permutit." Alcohols such as dulcitol (German Dulcit) are exceptions.

10. German names of acids should generally be translated by substituting *—ic acid* for "—säure." Some well established names are exceptions, as Zuckersäure (saccharic acid), Milchsäure (lactic acid), Valeriansäure (valeric acid), etc. When the names end in "—insäure" the translator *may* substitute *—ic acid* unless another acid already bears the resulting name; thus, Acridinsäure, acridic acid, but Mekoninsäure, meconinic acid, because meconic acid (Mekonsäure) is different. Names ending in "carbonsäure" are to be translated —carboxylic acid (not —carbonic acid).

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

ADSORBED MOISTURE AND WATER OF CRYSTALLIZATION IN CERTAIN COMMON DYES.[1]

By H. Wales and O. A. Nelson.

[ABSTRACT.]

VAPOR pressure-water content curves have been obtained for methylene blue, crystal violet, erythrosin, magenta and tartrazin, for the purpose of determining whether the water present in these dyes is adsorbed or held as water of crystallization. Crystal violet and tartrazin alone show hydrate formation. Further proof was obtained that the equivalent of one molecule of water in erythrosin is present as part of the molecule and a new theory of the structure of this dye is offered.

EMULSIONS OF MINERAL OIL WITH SOAP AND WATER: THE INTERFACIAL FILM.[2]

By Edward L. Griffin.

[ABSTRACT.]

IN an emulsion of mineral oil with soap and water, part of the soap is hydrolyzed, the fatty acids being dissolved by the oil droplets and the alkali remaining in aqueous solution.

Fatty acids may be kept from dissolving in the oil by the addition of excess alkali.

Part of the soap forms unimolecular films around the oil droplets. The average areas occupied by each molecule of sodium oleate, potassium stearate and potassium palmitate were 48, 27, and 30×10^{-16} sq. cm., respectively. These areas agree rather closely with those found for the corresponding fatty acids in unimolecular films on the surface of water.

In case there is insufficient soap to form a unimolecular film the emulsion is not stable.

The excess soap remains in water solution.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Am. Chem. Soc.*, **45** (July, 1923) : 1657.

[2] Published in *J. Am. Chem. Soc.*, **45** (July, 1923) : 1648.

EQUATIONS FOR VAPOR PRESSURES AND LATENT HEATS OF VAPORIZATION OF NAPHTHALENE, ANTHRACENE, PHENANTHRENE, AND ANTHRAQUINONE.[3]

By O. A. Nelson and C. E. Senseman.

[ABSTRACT.]

EQUATIONS for vapor pressures and latent heats of vaporization of naphthalene, anthracene, phenanthrene, and anthraquinone were calculated by applying the Clapeyron equation of state. The entropy of vaporization of these compounds was also calculated and the conclusion that they all form normal liquids was reached. The vapor pressure observed for each compound agrees closely with the calculated pressure.

CHANGES IN POWDERED ROSIN STORED IN CLOSED CONTAINERS.[4]

By F. P. Veitch and W. F. Sterling.

[ABSTRACT.]

SOME of the so-called constants of powdered rosin undergo pronounced changes within a short period of time, even when the rosin is stored in partially filled corked bottles. While the rate of change diminishes greatly after the first week, it continues at a significant rate for at least three weeks. At the end of six weeks the following changes had occurred: The acid number had decreased 5.3 to 9.3 points and the iodine number 47.3 to 52.2 points; the saponification number had increased 5.1 to 8.9 points and the melting point 8.9 to 11.3 degrees.

Obviously, therefore, samples of powdered rosin should not be prepared for analysis until the analysis is to be made.

Ferric Hydroxide as an Antidote for Arsenic. HORATIO C. WOOD (*Jour. Amer. Pharm. Asso.*, 1923, xii, 482-483) strongly defends the use of ferric hydroxide as an antidote in arsenic poisoning. Ferric hydroxide forms a relatively insoluble compound with arsenic, and thereby greatly retards the absorption of the latter. The insoluble compound is removed from the stomach by the vomiting which is an almost constant symptom of arsenical poisoning, or by the administration of emetics and laxatives. J. S. H.

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[3] Published in *Ind. Eng. Chem.*, 15 (June, 1923): 621.

[4] Published in *Ind. Eng. Chem.*, 15 (June, 1923): 576–577.

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BOOK REVIEWS.

CHEMISCHE TECHNOLOGIE DES STEINKOHLENTEERS MIT BERÜCKSICHTIGUNG DER KOKSBEREITUNG. By Dr. R. Weissgerber. 8vo, vii-139 pages, illustrations and index. Leipzig, Otto Spamer. Price, paper bound, $1.10 net.

The author of this work, a director of one of the German plants for producing and utilizing tar, has had a large experience in practical and analytical work. A thorough account is given of the present methods of differentiating the several important constituents of the crude tar. No one need be told that Germany has developed such industries to the highest point. Theodore Weyl, of Berlin, in the preface to his work on the "Sanitary Relations of the Coal-Tar Colors," said, "Thanks to the coöperation of theory and practice, the coal-tar color industry has conquered the world." The conquest has not been fully maintained of late years, for several of the nations which were joined against Germany have secured what may, in the terminology of the peace treaty, be called a mandate over some of the field, efficient plants for manufacturing coal-tar derivatives having been established in those countries.

A most interesting and valuable section of the work is that devoted to "low-temperature coking." We are not astonished to learn that this procedure was first applied in England. The same old story recurs often in the history of tar-technology, and, indeed, in other technologic lines. The first synthetic color was made in England, and it was Davy who first described the catalytic action of platinum on a mixture of sulphur dioxide and oxygen. The latter principle is now widely applied in the manufacture of sulphuric acid, but the details were worked out in Germany. The submarine and airplane are primarily American inventions, but it was left to Germany to demonstrate their use in war, and to bring them to a high degree of efficiency.

Low-temperature coking consists in distilling at not above 700°C., or somewhat below that point. The method was first applied in England to cannel coal, but the investigation of the fixed and volatile products was not pursued. Boernstein in 1906 found that coal began to emit gas at about 390° and between 400° and 500° yielded a tar that was quite different from that obtained by the ordinary high-temperature method. French and English investigators pursued the subject and obtained among other results special forms of volatile products by distilling under very low pressure. It was also found that the tar from the low-temperature process can be converted into high-temperature tar by transmission through red-hot tubes. During the war, the German coal-tar and coking plants studied the procedure extensively. Notwithstanding the interest that has been aroused in this matter and the promise of new and useful products, the low-temperature coking industry is still but slightly developed.

In the low-temperature distillation of coal, considerable amounts of water pass over, but this is not appreciably ammoniacal. The nitrogen remains in great part in the coke. The gaseous portion contains a large amount of methanes, but comparatively little of the olefin group or of free hydrogen. Burgess and Wheeler published a comparative table of the products of distillation of a sample of coal at 1100° and below 600°. The contrast in ingredients is marked. Fischer and Glaud gave comparative figures of the composition of samples of low-temperature and high-temperature cokes respectively from the same coal. The

most notable difference is in the content of hydrogen and nitrogen, the low-temperature coke containing far higher proportions of these than that produced at high point. Low-temperature coke burns with a smokeless flame, and as it contains considerable hydrogen has probably a decidedly higher heating power than ordinary coke. Referring to heating power leads the reviewer to express regret that the author uses WE for this unit. This is an abbreviation of a German term, but it is not evident from the symbol alone whether the unit is commensurate with B.T.U. or one of the Calories. It is to be regretted that so much yet remains to be accomplished in unifying nomenclature and symbolism in science. Some German journals are now using the abbreviation v.H for percentage instead of the almost universal and briefer %. German chemists continue to use "benzol," "toluol" and so on for benzene and its homologues. By general consent "ol" now indicates an alcoholic structure.

The fact that the gas obtained from low-temperature coking contains a large proportion of methanes seems to indicate that it may afford a source of lighter fuel for motor vehicles, and thus relieve the strain on petroleum. The lack of olefins will give a low illuminating power, but the days of gas as a general illuminant may be over. Gases from coal will probably pass into very extensive use for heating and for stationary motors. Anything that will increase the profits of by-product coking will be of advantage to the comfort of human-beings, for the smokiness of modern cities certainly diminishes the enjoyment of life.

The greater portion of the book is devoted to the ordinary (high-temperature) coking, of which an exhaustive and valuable treatise is given. The procedures are largely illustrated and the nature and methods of refining the several fractions of the subsequent distillations are given in detail. Numerous references to the literature are given and in appropriate form, that is, the year and volume are both given when the periodical uses both, and the volume is indicated in full-faced type, so much more satisfactory and so much less liable to error than the Roman numerals.

The work will be of great value to gas and fuel engineers and chemists. The text is clear and exact and the mechanical execution of the book excellent.

HENRY LEFFMANN.

INTRODUCTION GÉOMÉTRIQUE A L'ÉTUDE DE LA RELATIVITÉ. By Henri Marais. 191 pages, 8vo, paper. Paris, Gauthier-Villars et Cie. Price 7 Francs 50.

The theory of relativity has attracted a great deal of interest in France since its presentation, and a very large amount of literature has appeared in response to this interest. French physicists and mathematicians are by no means unanimous on the subject, and while many publications endorse the theory earnestly, dissent is also expressed in equally positive form.

In the work in hand, the author proposes to present under simple yet intelligible form, a sort of grammar of the mathematical language of relativity, from the standpoint of geometry. Euclidean and Riemann conceptions of space are discussed and the laws of invariance for linear transformations of any type, indicating the function performed by geometric views in the theories of relativity thus explained. The book will interest both mathematicians and

physicists, and will be of special service to those who are familiar with the principles of analysis and desire to study a special exposition of relativity. Some difficulties generally encountered in studying the theory will be eliminated.

HENRY LEFFMANN.

LES ISOTOPES. By A. Damiens, D.Sc. ix–115 pages and contents, 8vo. Paris, Gauthier-Villars et Cie. Paper bound, 12 Francs.

It is well known that the theory that matter is discrete, the ultimate particle being infinitely small and incapable of reduction, was due to the early Greek philosophers. Their views are known to us only through quotations by later writers, and the theory was practically ignored for many centuries, until Dalton presented it in a form that was generally accepted in physical science. His suggestions led to great advances in chemistry, among which was Berzelius' system of symbols, which, being based on atomic weights, gave a quantitative value to all formulas. For about a century, the atomic theory in substantially its original form was generally accepted, but investigations began to show that while the atom may be considered the unit of chemical action, it is itself made up of minuter particles or foci of energy. The positive nucleus (proton) and the electron are now familiar terms. With the discovery of the radio-active elements there came a new concept, that of elements that have atomic weights so close that they occupy the same places in the periodic table but are not identical. It is not necessary to set forth the details of these discoveries. There is abundance of literature on the subject. The work of Doctor Damiens, now under consideration, is a clear and comprehensive summary of the methods of investigation and of the results that have been obtained in this field. While strictly scientific, the book is written in a plain manner, avoiding intricate mathematical data, and thus serves to inform the intelligent reader as well as the scientist. The work of investigators of all nationalities is presented clearly and fairly. Lavoisier's dictum, that an element is a substance of which the weight cannot be changed by the chemical actions which it undergoes, is no longer accepted. The idea of the molecule, indeed, came early into the view of chemists, but they regarded with comparative indifference the data that were being brought out by physicists. Notwithstanding the great changes that have been made in the atomic theory by the discovery of the complex nature of the atom, this is still the chemist's unit for all stoichiometric procedures.

A remarkable result of the discovery of isotopes has been the tendency to return to the hypothesis of Prout, who postulated the view that all atomic weights are simple multiples of the atomic weight of hydrogen. This was an attractive view, and was probably accepted more from sentimental than scientific motives, but the researches of Stas and Dumas rendered it untenable. Chlorine, especially, stood out conspicuously with an atomic weight almost exactly intermediate between 35 and 36. The development of the knowledge of isotopes among elements not radioactive has eliminated most of the difficulties of Prout's view, for by certain mixtures of isotopic forms with whole number atomic weights, a fractional weight of the element as it occurs is the result. Thus chlorine being shown to have two isotopes, of weights respectively 35 and 37, the fractional figure is explained. The table of isotopes

given in the book is taken from the recent report of the International Committee on Chemical Elements with the addition of data on antimony published since that report appeared. The array of numbers shows in several cases isotopes with identical masses, although not the same elements. Thus argon and calcium have each an isotope of 40, although it is not considered that these are identical substances. Similarly, selenium and krypton have isotopes of 80 and 78. The term "isobares" is applied to such coincidences, a word a little unfortunate, "isobar" being a term well established in meteorology. There seems, however, no other term that can satisfactorily express the idea, and if the spelling and pronunciation are preserved with the final "e" in the chemical term, little confusion will result.

Doctor Damiens' book can be recommended to all who wish to learn the methods and results of the investigations that have so profoundly modified the views as to the constitution of matter. One interesting point is that a possibility of multiple isomerism in inorganic compounds is foreseen. Hitherto organic chemistry has been almost exclusively the field for such conditions, but our author points out that if chlorine and potassium have each two isotopes and platinum six, one hundred and twenty-six isomers of potassium chlorplatinate are possible.

HENRY LEFFMANN.

CHEMISCH-TECHNISCHE VORSCHRIFTEN. By Dr. Otto Lange, Technical High School, Munich. Third edition, enlarged and thoroughly revised. Vol. 1, Metals and Minerals. xxxvi–971 pages and index, 8vo. Leipzig, Otto Spamer. Price $8 net.

This work, now issued in a third edition, is to be complete in four volumes. The volume in hand comprises metals, alloys and products therefrom. The second volume will cover textiles, artificial and natural in the broadest sense; the third, oils, fixed and volatile, soaps, laquers, colors, water and sewage problems; the fourth, fertilizers, food and feed-stuffs, explosives. The treatment of all the subjects is comprehensive and extensive. Analytical data are not included, reference being made to works specially devoted to such matters. The author has been able to include a large amount of information by frequent reference to the literature, so that any one desirous of pursuing more intimately a given investigation can follow up the details in many directions. Especially valuable is the thorough reference to the patent literature of the more important nations. This is, of course, a prominent feature of technology, though a very large portion of such literature is disappointing, patent-office officials being often not very discriminating as to the merits or originality of claims filed. The French "reservation" "s.g.d.g." might well be added to all issues.

Chemical technology, says Doctor Lange, rests upon the knowledge of the principles of chemistry; it aims to follow the processes of nature, but to hasten or delay these, and changes raw materials into forms that are useful to mankind. Its purpose is purely practical, but its proper development cannot be secured without the assistance of the pure science, the search for truth for truth's sake. Tradition and recorded history inform us that man began very

early to manipulate the materials found in nature, but the beginnings of some of our most important and familiar industries are lost in the mist of antiquity. The cave-man, who decorated the caves of western Europe with remarkable paintings, and who engraved pictures of animals on bones and tusks, seems to have developed the making of both vegetable and mineral colors although, it is true, many of these materials are practically ready formed in nature. It is interesting to note that perhaps the beginnings of civilization may have been due largely to women. In the earliest period when human-beings lived mostly in enmity with each other except within the kinship, the man was occupied in hunting animal food or defending his family; the woman remained at home to take care of the children. It was probably her attempts to raise grain and other vegetables that led to a change from a nomadic to a stationary life, the first step in civilization. Her efforts at spinning and weaving led to the substitution of textiles for skins for garments, and it is likely that the first rude pottery was from her hands. The occurrence of some few metals in the free state, and the comparatively easy reduction of others, led to early development of metallurgy, though it is generally held by anthropologists that stone implements for domestic use and for hunting and war preceded the employment of metals. The Odessey mentions the hardening of steel by immersion of the heated mass in water, specifically describing the preparation of the battle-axe.

We live to-day in an industrial civilization. Historians speak of the civilizations of the past, Egyptian, Babylonian, Greek, Jewish, Roman, but these had only limited resemblances to our modern life. In the basic impulses of human nature, of course, the story is the same, but to-day the problems socially and scientifically are industrial, and chemistry comes into play throughout the field. It is also the dominating science in the medical field, for physical chemical principles and methods are now almost entirely the basis of theories in biology and hygiene. To this industrial physio-chemical age, therefore, the book in hand appeals. It is indispensable to the worker, whose name is now "Legion," in the laboratory or in the direction of the factory. All these will find it a most serviceable and satisfactory guide. The amount of material here collected and arranged is immense. No narrow nationalism has restricted the scope of Doctor Lange's search. The war, as might be expected, has interfered with some verifications, but these relate to certain data in regard to location of patent literature. Yet in view of this comprehensiveness of reference it is at first somewhat puzzling to note from the list of periodicals consulted, the absence of such important ones as the *Journal of the Society of Chemical Industry* and the *Journal of Industrial and Engineering Chemistry*, also that no French journals are listed. The explanation is that for a large part of the non-German literature, reliance has been upon the abstracts in the German periodicals. That the non-consultation of leading British and American periodicals in this field has not been due to war conditions is shown by the fact that the *Journal of the Chemical Society* and the JOURNAL OF THE FRANKLIN INSTITUTE are enumerated as original sources. The use of abstracts is frequently unavoidable. German abstracts are usually comprehensive and trustworthy, yet it is somewhat unsafe to rely on secondary

sources. The extent of Germany's specialized literature in this field is shown by the enumeration of twenty-two publications under the title "Zeitschrift."

The book is divided into three main groups: A general discussion of metals, and their working, such as alloying, polishing, electrolytic deposition, etching and similar procedures; a special part in which the individual metals are described and their technology set forth, in which articles some history of the metal is given; a third section on mineral colors. It will be seen, therefore, that while the bulk of the work is on metallurgy, the scheme upon which it is based is so comprehensive that a large amount of accessory matter is included, and its usefulness as a work of reference thereby much enhanced. Use of the book is materially assisted by a good table of contents and an index of thirty-nine closely printed pages. The references are to paragraphs, not to pages, a fact of which the user is informed by a line on each page of the index. This method is useful when, as in the case, the text is closely printed, but it would be well to carry the paragraph numbers at the head of the page.

The work is a monumental summary of data in the field to which it is devoted, and gives an indication of the value the complete work will have. Doctor Lange deserves the thanks of the industrial chemist for his labor in this line, and the house of Otto Spamer deserves similar obligations for the manner and form of the publication.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 160, An Airship Slide Rule, by E. R. Weaver and S. F. Pickering, Bureau of Standards. Twelve pages, illustrations, quarto. Washington, Government Printing Office, 1923.

This report describes an airship slide rule developed by the Gas-Chemistry Section of the Bureau of Standards, at the request of the Bureau of Engineering of the Navy Department. The development of this slide rule was requested by the Navy because of the successful results which had been reported of the Scott-Teed rule which had been developed and used by the British naval air service. It is intended primarily to give rapid solutions of a few problems of frequent occurrence in airship navigation, but it can be used to advantage in solving a great variety of problems, involving volumes, lifting powers, temperatures, pressures, altitudes, and the purity of the balloon gas.

The rule is graduated to read directly in the units actually used in making observations, constants and conversion factors being taken care of by the length and location of the scales. In order to simplify as much as possible the manipulation of the rule, absolute accuracy has in some cases been sacrificed to convenience. Generally this has been necessary only in those cases in which the data upon which the computations will be based are not subject to accurate observation.

It is thought that with this rule practically any problem likely to arise in this class of work can be readily solved after the user has become familiar with the operation of the rule; and that the solution will, in most cases, be as accurate as the data warrant.

Report No. 163, The Vertical, Longitudinal, and Lateral Accelerations Experienced by an S.E.5A Airplane While Manœuvring, by F. H. Norton and

T. Carroll. Five pages, illustrations, quarto. Washington, Government Printing Office, 1923.

This investigation was carried out by the Langley Field Laboratory for the purpose of measuring the accelerations along the three principal axes of an airplane while it was manœuvring. The airplane selected for this purpose was the fairly manœuvrable S.E.5A and the instruments used were the N.A.C.A. three component accelerometer and the N.A.C.A. recording airspeed meter. The results showed that the normal accelerations did not exceed 4.00 g. while the lateral and longitudinal accelerations did not exceed 0.60 g.

Report No. 165, Diaphragms for Aeronautic Instruments, by Mayo D. Hersey, Bureau of Standards. Thirty-two pages, illustrations, plates, quarto. Washington, Government Printing Office, 1923.

In this report is presented an outline of historical developments and theoretical principles, together with a discussion of expedients for making the most effective use of existing diaphragms, and a summary of experimental research problems.

Flexible diaphragms actuated by hydrostatic pressure form an essential element of a great variety of instruments for aeronautic and other technical purposes. The various physical data needed as a foundation for rational methods of diaphragm design have not, however, been available hitherto except in the most fragmentary form.

Report No. 168, The General Efficiency Curve for Air Propellers, by Walter S. Diehl, Bureau of Aeronautics, Navy Department. Eleven pages, illustrations, quarto. Washington, Government Printing Office, 1923.

Report No. 168 is a study of propeller efficiency, based on the equation

$$\pi = \left(\frac{V}{\pi ND}\right) \cot (\varphi + \gamma)$$

where

V = speed of advance.
N = revolution per unit of time.
D = diameter of the helix described by the particular element under consideration.

$$\varphi = \tan^{-1}\left(\frac{V}{\pi ND}\right)$$

and

$$\gamma = \tan^{-1}\left(\frac{D}{L}\right)$$

It is shown that this formula may be used to obtain a "general efficiency curve" in addition to the well-known maximum efficiency curve. These two curves, when modified somewhat by experimental data, enable performance calculations to be made without detailed knowledge of the propeller. The curves may also be used to estimate the improvement in efficiency due to reduction gearing, or to judge the performance of a new propeller design.

Report No. 170, A Study of Longitudinal Dynamic Stability in Flight,

by F. H. Norton. Nine pages, illustrations, quarto. Washington, Government Printing Office, 1923.

This investigation was carried out for the purpose of studying experimentally the longitudinal dynamic stability of airplanes in flight. The airplanes selected for this purpose were a standard rigged VE-7 advanced-training airplane and a JN4h with special tail surfaces. The airplanes were caused to oscillate by means of the elevator, then the longitudinal control was either locked or kept free while the oscillation died out. The magnitude of the oscillation was recorded either by a kymograph or an airspeed meter. The results show that the engine speed has as much effect on the period and damping as the airspeed, and that, contrary to theory as developed for small oscillations, the damping decreased at the higher airspeeds with closed throttle.

PUBLICATIONS RECEIVED.

Chemisch-Technische Vorschriften. Ein Handbuch der speziellen chemischen Technologie insbesondere für chemische Fabriken und verwandte technische Betriebe enhaltend Vorschriften aus allen Gebieten der chemischen Technologie mit umfassenden Literaturnachweisen von Dr. Otto Lange. 3te, erweiterte und völlig neubearbeitete Auflage. I Band: Metalle und Minerale. 1011 pages, 8vo. Leipzig, Otto Spamer, 1923. Price, in paper, $8; bound, $9.

Les Isotopes. Par A. Damiens. Preface de M. Jean Perrin. 118 pages, illustrations, plate, 8vo. Paris, Gauthier-Villars et Cie., 1923. Price, 12 Francs.

Institute of Government Research. Service Monographs of the United States Government No. 26. The Bureau of Public Roads: Its History, Activities and Organization. By W. Stull Holt. 123 pages, 8vo. Baltimore, Maryland, The Johns Hopkins Press, 1923. Price, $1.

La Relativité Vraie et la Gravitation Universelle. Par Georges Fournier. 130 pages, 8vo. Paris, Gauthier-Villars et Cie., 1923. Price, 7 Francs.

Chemische Technologie des Steinkohlenteers mit Berücksichtigung der Koksbereitung. Von R. Weissgerber. 141 pages, illustrations, 8vo. Leipzig, Otto Spamer, 1923. Price, in paper, $1.10.

Introduction Géométrique a l'Étude de la Relativité. Par Henri Marais. 191 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1923. Price, in paper, 7 Francs 50.

Canada, Department of Mines, Mines Branch. Summary report of investigations made by the Mines Branch during the calendar year ending December 31, 1921. 346 pages, illustrations, plates, maps, 8vo. Ottawa, King's printer, 1923.

La Simultanéité Générale et le Temps Universel. Par le lieutenant-colonel Corps. 20 pages, 8vo. Paris, Gauthier-Villars et Cie., 1923. Price, 3 Francs 50.

Red Telefonica de Guipuzcoa (Espana). Descripcion, historia y estadistica. Par el Ingeniero-Director de la Red D. Ignacio M. Echaide. 40 pages, illustrations, map, 8vo. Villafranca de Oria, 1923.

Comparison of Plante Type Secondary Batteries in Our and Foreign Countries in Respect of their Characteristics and Durability. Part 1, Characteristics of Plante Type Secondary Batteries chosen for our first experiment.

By Sakae Makio, Electrotechnical Laboratory, Ministry of Communications, Japan. 37 pages, illustrations, plates, tables, diagrams, 8vo. Tokyo, 1923.

The Wind Factor in Flight: An Analysis of One Year's Record of the Air Mail. By Willis Ray Gregg and Lieutenant J. Parker Van Zandt. 15 pages, diagrams, quarto. Reprinted from *Monthly Weather Review*, March, 1923, 51: 111–125. Washington, Government Printing Office, 1923.

National Advisory Committee for Aeronautics. Technical Notes No. 148, The Flexible Mounting of an Airplane Engine, by K. Kutzbach. 6 pages, quarto. No. 150, Notes on the N.A.C.A. Control Force Recorder, by H. J. E. Reid. 4 pages, photographs, quarto. No. 151, Tests on Built-up Airplane Struts having Initial Tension in Outside Fibres, by T. A. Schwamb and C. S. Smith. Abstracted by John G. Lee. 6 pages, illustrations, diagrams, photographs, quarto. No. 152, Thrust and Power Required in Climbing, by Georg Koenig. 19 pages, illustrations, quarto. Washington, Committee, 1923.

Royal Institution of Great Britain. Weekly Evening Meeting. Friday, January 16, 1920, Low-temperature Studies, by Sir James Dewar. 38 pages, illustrations, 8vo. Friday, June 10, 1921, Absolute Measurements of Sound, by Arthur Gordon Webster, D.Sc. 7 pages, illustrations, 8vo. Friday, March 3, 1922, Microscopic Parasites and their Carriers, by C. Morley Wenyon, C.M.G. 19 pages, illustrations, 8vo. Friday, June 2, 1922, Gilbert and Sullivan, by Hon. Maurice Baring. 14 pages, 8vo. Friday, February 23, 1923, The Interior of a Star, by A. S. Eddington, F.R.S. 15 pages, 8vo. Friday, February 9, 1923, Rothamsted and Agricultural Science, by Sir E. John Russell. 13 pages, illustrations, 8vo. Friday, March 9, 1923, Sunlight and Disease, by C. W. Saleeby, M.D. 6 pages, 8vo. Friday, April 20, 1923, The Growth of the Telescope, by William J. S. Lockyer, Ph.D. 13 pages, illustrations, 8vo. Friday, May 4, 1923. The Origins of the Conception of Isotopes, by Frederick Soddy, F.R.S. 13 pages, illustrations, 8vo. London, Royal Institution, 1923.

Absorption Coefficients for Homogeneous X-rays. EDWARD G. TAYLOR. (*Phys. Rev.*, Dec., 1922.)—The absorption coefficients for several organic liquids were measured for X-rays of wave-length .715 Ångstrom unit. The main question approached was this, "Is absorption of X-rays an atomic property?" Does an atom of carbon always absorb to the same extent no matter in what company it finds itself? Two pairs of isomers, pinene and limonene, $C_{10}H_{16}$, and ethyl acetate and methyl proprionate, $C_4H_8O_2$, were tested. "Within the limit of the experiment the molecular absorptions are the same for the compounds of the same composition and offer additional evidence in favor of the view that X-ray absorption is an atomic property." The data calculated for hydrogen are, however, discordant and oxygen seems unwilling to fall in with the additive relation. The problem therefore must remain *sub judice* until further light comes. May it not be hoped that Lieutenant Taylor will continue to search for the solution with the same enthusiasm with which he conducted his course on X-rays at the A.E.F. University in Beaune? G. F. S.

CURRENT TOPICS.

Plant Resources for Motor Fuel.—Under this title, the *International Review of Science and Practice of Agriculture* (n. s., 1923, I, 208) collects the results of study of nine articles that have recently appeared giving data of the practicability of the manufacture of alcohol for motor purposes. H. I. Cole, chemist to the Bureau of Science, Manila, Philippine Islands, treats at length of the experiments undertaken in the Islands to ascertain the comparative economy of manufacturing alcohol from several of the raw materials there available, and reports that the Nipa palm (*Nipa fructicans Wurmb.*) and blackstrap molasses offer the best and cheapest methods. Alcohol has several advantages as a motor fuel. It burns clean—without carbon deposit—the running of the engine is smoother than with the common hydrocarbon fuels, it stands high initial compression without knocking, lubrication difficulties are less, and, as far as observed, no corrosion has appeared in the valves, and no acid in the exhaust. Certain difficulties will doubtless disappear after further experience.

Mixtures of alcohol with other combustibles have given better results than alcohol alone. In South Africa, a mixture termed "natalite" (55 per cent. of rectified alcohol, 44.9 per cent. of ether, 1.11 per cent. kerosene and 0.56 per cent. of pyridin) has been successful. The percentages are doubtless by volume. Important data are given as to the cost of making alcohol in the Philippines, based upon large experience. The estimated daily cost of operating a plant producing 1000 gallons per day is $138.29, which is about 14 cents per gallon. The figures include labor, fuel, interest, depreciation, "etc." Unless the "etc." includes the cost of the material, which does not seem likely, the actual cost per gallon will be higher than that calculated from the above total. It is not stated what strength of alcohol is produced, but presumably the calculations are made on the 95 per cent. basis. The Nipa palm is stated to be the most important and cheapest source of alcohol, as the plant grows in uncultivated places and the sap is drawn from near the ground, thus obviating the necessity of climbing. The alcoholic product of this plant has, however, been heretofore mostly employed as a beverage, and its applicability as a fuel has only recently been put to the test. The sap passes quickly into fermentation, usually arriving at the distillery with an appreciable alcohol content, though complete fermentation requires considerable time. To prevent loss by conversion into acetic acid, a mixture of the sap with molasses is usually employed. At present the palm is found extensively distributed in the Philippines and north Borneo, some 400,000 acres being estimated as covered by it.

Vegetable oils have been studied as materials for motor fuel. The investigation has been initiated on account of the danger of using the inflammable hydrocarbons in a hot climate. The ordinary vegetable oils are stated to be applicable to motors of the Diesel and semi-Diesel type. For engines of the latter type, experiments in Europe have shown that palm oil may be used as fuel without any serious modification of the engine details. The calories of vegetable oils are, of course, high. The possibility of corrosion owing to the fact that palm oil has high acidity seems to have been eliminated by the experiments.

The motor vehicle problem becomes of great importance in districts like South Africa in which the tsetse fly interferes with raising of draft animals. The possibility of using the native products for fuel will be of great advantage. The high prices for the hydrocarbon fuels with the likelihood that these will not be materially reduced in the future, constitute important reasons for experiment along the lines indicated in the article. Up to the present, investigations have centred on palm oil, but it is to be hoped that a much wider range of experiment may be soon undertaken. The substitution of such materials as alcohol or fixed oils would have the great advantage of eliminating to a large extent the fire risk that is now associated with the hydrocarbon fuels. H. L.

Forensic Chemistry in the Punjab.—The report of Lieutenant-Colonel J. A. Black of the Royal Medical Service, on the work of the Chemical Laboratory of the Punjab, gives a vivid and interesting insight into the problems that are encountered by a chemist in a mixed population of Hindus and Mohammedans. The Punjab is a district in northwestern India stretching from the foot-hills of the Himalayas to a comparatively low land. It is watered by the Indus, of which there are five tributaries. The name is derived from a Hindu word meaning "five." Notwithstanding these rivers, the majority of the district is hot and dry, especially from April to September. The area is about 136,000 square miles, somewhat smaller than the State of Montana. The population is about 20,000,000, of which about half are Mohammedans and the greater portion of the remainder Hindus.

The characteristic of the chemical work in this laboratory is examinations in cases of poisoning. Homicidal and suicidal poisonings are extremely common. Suicides often occur from what would be considered in other countries as very trifling motives. Homicidal poisoning is occasioned by about the same class of motives that are active elsewhere. Accidental poisonings, due to ignorant use of dangerous drugs or the negligence of drug vendors, are also more frequent than in Europe and America. Arsenic is very largely used, on account of the resemblance of its symptoms to those of cholera, a disease often very prevalent in the district. Opium and Datura seeds are also frequently used, the former mostly for suicide and infanticide,

the latter for drugging food and drink, to aid in commission of robbery. An account is given of the methods of the Thags (commonly known in English as "Thugs") who mostly use Datura seeds. Aconite is also used in the places in which it is found. These four poisons cover about 90 per cent. of the cases of poisoning found in the Punjab. In consequence of this limitation, the task of the toxicologist is comparatively simple. A notable difference exists between the manner in which the expert evidence is given in India and in western nations. The India chemist is comparatively rarely required to appear in court. He makes a written report, which is read. He is, therefore, not subject to cross-examination. Doctor Black inclines to favor this method, though he acknowledges that it is not without defects. As a matter of fact, it is a highly objectionable method, but it has been adopted largely because of the great extent of the district over which the expert's duties extend. Crime is greater in proportion to the population than in more highly civilized countries—at least, detected crime is greater—and personal attendance on trials would require a large body of chemists.

Physiologic methods of detecting poisons are necessary in many cases, and it is interesting to read the statement that the animals are treated with as much care as possible. This observation is probably meant to avoid any criticism from that numerous and influential portion of the British public opposed to animal experimentations. Blood differentiation is, of course, not infrequently required. The precipitin tests have been found satisfactory, and the application of them has led to conviction in a number of cases. A case is described in which a stain was shown to be a mixture of camel's and human blood, the former identified by the shape of the red compuscles, materially different from ordinary mammal blood, and the latter detected by the precipitin test.

The work of the laboratory is by no means limited to the toxicology field. Food adulteration is extensive. A special and dangerous line is the examination of explosives in packages and letters. During the war, many articles of household use were seized by the authorities under the suspicion of being intended for employment against the government, so that a curious and miscellaneous collection of articles was referred to the chemist. As might be expected, illicit drugs are often found, especially cocaine. Drugs of this type, found to be of good quality, are turned over to the medical authorities. A great deal of the illicit importation of cocaine was in German hands before the war. The use had reached such extensive development that there was one time in the laboratory confiscated material, the money value of which at the ordinary bazaar rates was estimated at about $160. A great variety of problems not connected with medical matters has also been considered in the laboratory, such as the best method of waterproofing fabrics for troops, the cause and prevention of corrosion of copper plates in boilers, the amount of barium carbonate required to

poison rats, for prevention of spread of plague, and whether a certain antiseptic preparation could be safely used in water.

The government has recently improved the laboratory very much, having spent about $50,000 in new buildings and equipment. Dust is very much of an annoyance, and it is intended to sink a well for the express purpose of aiding in the development of lawns and the raising of trees so as to overcome this annoyance and also to beautify the grounds. The laboratory was located at Lahore, about sixty years ago, primarily to deal with the criminal incidents among the native population. Cases of poisoning are by no means limited to human beings. Domestic animals are often victims. A peculiar method of animal poisoning is often noted. Seeds of *Abrus precatorius* are pounded and made into a paste with water. The paste is shaped into a narrow, pointed, needle-like form, which when dry becomes very hard. It is fitted into a small cavity in a bamboo stick, which serves as a handle, pushed under the skin of the animal and the handle removed. An intense local inflammation is soon set up, which results in the death of the animal in a few days if the wound is not detected in time and the mass removed. H. L.

Total Reflection of X-rays. A. H. COMPTON. (*Phil. Mag.*, June, 1923.)—While "direct attempts to measure the index of refraction of different substances of X-rays have hitherto failed," yet certain features of the effects produced upon the rays by crystals have indicated that they are refracted when they enter the material of the crystal. Duane and Patterson have found a difference between the wave-length of the tungsten line obtained from the first order spectrum and that got from the second order, when calcite is used. This leads to the conclusion, derived on grounds of theory, that for the type of X-ray used the index of refraction for calcite is 8×10^{-6} less than unity. From another point of attack, the Drude-Lorentz theory of dispersion, utilizing what is known of the number of electrons per unit of volume, the frequency of vibration, etc., gives just about the same index of refraction as the other method. This agreement furnishes good presumptive evidence that refraction really exists. If refraction does take place and if, further, the index of refraction of X-rays entering calcite from air is less than unity, then we have a case of refraction analogous to that occurring when a ray of ordinary light passes from water into air. This being so, total reflection should exist. Does it exist? A narrow beam of X-rays fell upon a crown glass mirror at a large angle of incidence, or a small glancing angle. The reflected ray let into a chamber and the resulting ionization was measured. A study of the reflected radiation showed that the reflection was not diffuse but specular in character, though not perfectly regular. Now, if total reflection really takes place, the energy of the reflected ray should equal that of the incident ray. Measurement proved the energy of the former to equal 91 per cent. of that of the

latter. It may therefore be concluded that something closely approaching regular, total reflection occurs at the surface of the glass mirror. One method of determining the index of refraction of ordinary light for a substance is by measuring the angle at which total reflection first shows itself. The author now proceeds to apply this method to X-rays. For glass the critical glancing angle (90° the angle of total reflection) is 10′, for lacquer 11′ and for silver $22\frac{1}{2}'$. The wave-length of the X-rays used was 1.279 Ångstrom units. The indices of refraction are calculated from the relation, index equal cosine of the critical glancing angle. All three indices are less than unity and by these quantities: Glass, 4.2×10^{-6}; lacquer, 5.1×10^{-6} and silver, 21.5×10^{-6}. All these values agree quite well with the values computed from the Drude-Lorentz formula, which connects the index of refraction with the number of electrons per unit volume of the medium and the frequency of the radiation. It is quite advantageous to have the validity of this relation established. From it can be calculated the index of refraction of substances containing only lighter atoms, or the wave-length of an X-ray beam can be computed from a determination of its index of refraction, or, again, from a knowledge of the index refraction and of the wave-length it is possible to learn the number of electrons per atom which are affected by the incident rays. Professor Compton holds that the electronic numbers thus obtained are more reliable than those got by the two previously existing methods, *viz.*, scattering of alpha-rays by atomic nuclei and measurement of the intensity of scattered X-rays.

It is suggested that by total reflection a platinum mirror be used in order to select short wave-lengths from a beam of X-rays.

When X-rays were young, it seemed impossible to show that they did any of the things done by light. Gradually it is being shown that they possess all the properties of light. This paper definitely adds refraction and total reflection to the list. G. F. S.

A Photographic Study of Sound Pulses Between Curved Walls and Sound Amplification by Horns. A. L. FOLEY. (*Phys. Rev.*, December, 1922.)—"That the sound energy falling upon the ear or other form of sound receiver may be considerably increased by placing the receiver at the small end of a conical horn is a matter of common observation." This increase in intensity is often explained by reference to the progressive concentration of the energy into smaller and smaller volumes of air as the narrow end of the tube is reached. Dayton C. Miller, on the other hand, attributes the effect to resonance "The effect of the horn is to reinforce the vibrations which enter it due to the resonance properties of the air enclosed by the horn. . . . The horn is an air resonator. . . . the response below the fundamental of the horn is very feeble."

A cylindrical sound wave was started by a linear discharge of electricity between two knobs. A very short time later a second electric

spark is produced at a position to one side of the first. The light from this casts the shadow of the sound wave expanding from the first spark upon a photographic plate. The existence of the shadow is due to the refraction of the light while passing through the condensation of the wave. If a series of light sparks is produced at brief intervals, the successive shadows on the plate will be circles of progressively larger radii. To study the passage of sound waves through a straight tube, a curved tube, a megaphone and a conical horn (ear trumpet) the author arranged about the axis from which the wave started four combinations of plates simulating these transmitting devices. Six photographs were taken at an average interval of .00003 second. "As would be expected, all six pictures showed that the waves passed through the straight tube and megaphone without appreciable reflection, and that the megaphone wave suffered the greater attenuation. . . . All the pictures show that there was energy reflection in every case except when the wave front was at right angles to the surface and the motion of the air parallel to the surface of the tube. In the case of the horn there was continuous reflection from one end to the other, even at the small end where the angle of the cone is very small. In the case of the crooked tube there were successive reflections. For the crooked tube show respectively an emerging and emerged wave much more attenuated in the case of the straight tube of the same size. A considerable portion of the wave energy appears to be trapped inside the tube. However, it will be observed that the reflected waves in general were headed toward the outer part of the tube. This is not true, however, of the horn. Here the advancing wave shows unmistakable evidence of intensity increase or condensation, and that it emerged from the small end of the horn considerably amplified. But most of the energy was lost as far as the small end of the horn is concerned. The lost energy was contained in the reflected waves which, as the photographs show, headed the wrong way—'backing out' of the horn."

Intensity measurements of the condensing power of a horn were made both by a Rayleigh disc and by a Webster phonometer. When the area of the large end of the horn was 256 times that of the small end, the intensity at the small end was only about 9 times as great as at the large end.

The author concludes that the "condenser" theory of a conical horn receiver is not tenable and that the amplification of sound at the small end is due both to resonance and to condensation. "Sound pulses do not 'glide about bends' in tubes and 'slip' along slanting walls 'without appreciable reflection.'" "Much of the energy of a wave entering the large end of a conical horn is reflected and eventually leaves the horn at the end it entered. The wider the horn the greater the per cent. of energy thus lost."

It is hoped that Professor Foley will find time to solve the vexed problem of the whispering gallery by the powerful experimental method that he has perfected. G. F. S.

The K.D.B. Process of Color Photography. (*Rev. d'Optique*, Jan., 1923.)—When a corrected lens is giving an image of an object, a part of the lens can be covered up without interfering with the production of the image by the uncovered portions. Similarly different zones of the objective can be covered with selective color filters and each will continue to produce its independent image. Let three monochromatic filters, red, green and blue, be placed in the plane of the diaphragm in the form of bands side by side. Then the image on the ground glass will appear unchanged because the light traversing each filter will produce its own image and the three superimposed colored images will reproduce the natural color of the object. Now at the focus let there be placed a tiny lens of necessarily very short focus. This will project on the ground glass, a little beyond it, an image of the three bands of the filter. This image constitutes that part of the general image of the object contributed by the light impinging on the lens.

As an object to be photographed let us take a red point and for the glass plate let us substitute a sensitive panchromatic film. The red light from the point will pass through the red filter but not through the green or blue ones. The lens will project on the film no light from these two filters, but it will form a small red image of the red filter and the portion of the film under this will be blackened, while the adjacent parts corresponding to the missing blue and green images will be unaffected. The positive will be clear under the red image and black under the positions of the two other colors, as well as over the rest of the plate. Next for projection put the positive in the former position of the ground glass plate and illuminate it by white light. Only through the transparent part corresponding to the red image can the light pass. This transmitted white light will be directed by the optical system to the red part of the color filter, will emerge as red and will form a red image of the point on a screen outside of the objective. If the original point were yellow, then light from it would get through the red and the green screens and images of these parts of the screen would form on the plate. Upon reversal of the direction of the light for projection, white light would get through the positions on the positive of the red and green images. These two parts of the filter would receive this light and would transmit red and green light, respectively, and on the screen the superposition of the red and the green images will reproduce the yellow point.

In this process the sensitive layer is supported by a transparent solid whose surface on the side away from the film consists of a multitude of tiny convex surfaces acting as lenses. Each of these functions as does the single lens above discussed. On the film behind each of these, if a white object be photographed, there forms a tiny image of the color screens. The diameter of these lenses must not exceed .04 mm. A die with 520 lenses per sq. mm. was made by hand and from this the gelatin film was moulded into the requisite hillocky form.

As advantages it is claimed that but a single image is necessary for photography in colors, that the same film permits projection in black and white or in colors, that the simplicity of the process makes it accessible to all, that commercial photographic and projection apparatus can be employed, including moving picture apparatus. To use existing apparatus it is necessary only to put in the plane of diaphragm the three color screens, and to employ K.D.B. films.

K.D.B. appears to be the result of combining the initials of Messrs. Berthon and Keller-Dorian, the inventors. G. F. S.

The Spectrum of the Aurora Borealis and the Upper Layers of the Atmosphere. L. VEGARD. (*Comptes Rendus,* April 3, 1923.)—In the Geophysical Institute at Tromso a systematic investigation of the spectrum of the aurora borealis was conducted during the summer of 1922. Thirty-three lines and two bands were found, nearly all of which can be attributed to nitrogen. There are, however, four lines which cannot be ascribed to nitrogen, hydrogen, helium or oxygen. Their wave-lengths in Ångstrom units are 3208.3, 3432.7, 4182.5 and 5578.4, the green ray. No trace of lines due to hydrogen or to helium was obtained even after very long exposure. Mixtures of nitrogen and hydrogen and again of nitrogen and helium were made luminous by cathode rays in the laboratory. A comparison of the light then emitted with the spectrum of the aurora led to the conclusion that "the pressure of atmospheric nitrogen at a height from 100 to 120 km. is greater than the pressure of hydrogen and of helium. At these altitudes such a layer of hydrogen and of helium as has been generally believed in cannot exist."

Some spectrograms were taken of the upper edge of an aurora while others were obtained from the lower edge of the same aurora. The green ray, whether from the upper or the lower edge, bore the same relation to the nitrogen bands found. This shows that the gas emitting this ray must have the same molecular weight as nitrogen, else a change of elevation of from 40 to 60 km. would cause a difference in relative intensity. The author therefore attributes the green ray to nitrogen and for good measure concedes to it also the three other unclaimed lines.

There remains still this to be explained. How can the light of the aurora come sometimes from a height of 500 or 600 km.? "The best supposition is a strong ionization of the upper layers by X and gamma rays from the sun. . . . The effect of the electric charge on the distribution of pressure will be similar to that of a diminution of molecular weight. Moreover the heavy electric charge on the nitrogen in the upper regions furnishes an explanation of how this element emits in the aurora lines not hitherto observed in the laboratory. The ionization so far attained in the laboratory has been insufficient."

G. F. S.

The Periodic Opacity of Certain Colloids in Progressively Increasing Concentrations of Electrolytes. J. HOLKER. (*Proc. Royal Soc.*, A719.)—The colloid chiefly studied was the emulsoid human serum, which had been previously inactivated by heating. To the serum was added a solution of sodium chloride and the opacity of the resulting liquid was measured. "With low concentrations of saline from 0 to 0.96 per cent. the opacity of the serum became less and less until it reached a minimum. Beyond 0.96 per cent. saline it increased steadily to a maximum at 2.24 per cent. and so on." No less than eleven oscillations were observed, the final maximum being attained with 24 per cent. of added sodium chloride as the net percentage concentration. As more and more of the saline solution was added the maxima and the minima both occurred at higher degrees of opacity.

The color of the light employed in testing the opacity was varied and new curves connecting opacity and concentration were plotted. "While the general level of the curves and the amplitude of the periods varied with the color of the incident light, the length of the corresponding periods was remarkably constant. These experiments, therefore, suggest that the periodic opacity of serum in progressively increasing concentrations of sodium chloride cannot be due to interference phenomena, since in the latter case the length of the periods would have varied with the colour of the incident light." The concentration of the serum also was varied. "The periodic character of the curve persisted to a high degree of dilution of the serum, and both the amplitude of the oscillations and their number increase with the concentration of the serum." Lastly a series of determinations was made at different temperatures. "At the temperatures of 20°, 30°, 40° and 56° C. the periodic phenomenon was well marked, and the amplitude of the periods increased with the temperature, so that at 56° C. it was very pronounced. On the other hand, the length of the corresponding periods remained the same for all the temperatures." At temperatures still higher irregularities manifested themselves.

When calcium chloride was substituted for sodium chloride quite marked differences in the results came to light. The initial effect of the addition of the calcium solution was to increase the opacity while the wave-lengths as well as the amplitudes of the calcium curves are different from the corresponding quantities in the sodium curves. All the neutral salts examined caused the periodic change in opacity. With HCl the periodic character of the curve was completely lost. With NaOH traces of the periodicity remained. G. F. S.

THERE are alloys possessing considerable thermo-electric powers that are too brittle to be made into wire. R. HASE (*Z. f. Phys.*, vol. 15, No. 1) shows how to utilize such substances for thermo-elements.

G. F. S.

What Limits the Ultra-violet Spectrum of Sunlight? J. DUCLAUX and P. JEANTET. (*Jour. de Physique et le Radium,* March, 1923.)—The limit of the solar spectrum toward the short wave-lengths is at about 2900 Ångstrom units. Fabry and Buisson have demonstrated that this is due to ozone in the high atmosphere. No great quantity of this gas is requisite to cut off the spectrum at the point stated, and to keep from traversing the atmosphere any radiation between the wave-lengths 2900 and 2100 Å. However, the absorption band of ozone stops at 2100 Å. Why, then, is there not found in the solar spectrum at the earth's surface wave-lengths shorter than this? Perhaps these short waves are absent when the sunlight reaches the confines of our atmosphere. This is improbable, because the light emitted by the sun is much like that coming from a black body at 6000° C., and such a body radiates a measurable quantity of energy at wave-lengths shorter than 2000 Å. Furthermore, the formation of ozone in the outer parts of the atmosphere argues for the presence there of short wave-lengths. Experiment convinces the authors that a layer of ozone lets light through of wave-lengths from 2100 to 1850 Å. This substance is thus excluded as the cause as are also CO_2, water vapor, hydrogen and the rare gases, some for lack of adequate quantity and others for lack of proper absorption. Oxygen and nitrogen would be worth investigating thoroughly did not ammonia gas by itself furnish a reasonable solution of the difficulty. From observations made on the absorption exerted by this gas the authors conclude that all radiation shorter than 2020 Å. would be extinguished by a layer of .5 mm. ammonia gas at 760 mm. pressure, on the assumption that no other gas has any part in such absorption. This quantity of ammonia uniformly distributed throughout the atmosphere would amount to .047 mg. per cubic metre of air. Measurements on the ammonia content of the air range from 0 to .092 mg. per cubic metre. G. F. S.

The Minimum Audible Intensity of Sound. C. M. SWAN. (*Proc. Am. Acad. Arts and Sci.,* 58-12.)—From the time of the first quantitative determination of this up to the present there has been no lack of interest in the subject, but the results have been discordant. In 1922 two determinations for the same pitch were published and one was more than four times as large as the other. Some measurements were based on the law of inverse squares where the law could not possibly hold, others were interfered with by wind or by the presence of birds. In many cases no account was taken of the reflection of surfaces.

In the present investigation recourse is had to the large body of experience collected in connection with the work of Sabine at Harvard. A vibrating circular diaphragm closes a hole of the same shape in the door of a room within which the observer is stationed. A formula is derived connecting the energy per square centimetre per

second that just produces an audible effect with other measurable quantities, one of which is a measure of the time of decay of the sound within the room. The observer was placed in a box so that his clothing would not absorb the sound. A series of reflectors were shifted about to eliminate the effect of the formation of acoustical interference patterns. Two persons were used in turn to take the time required for the sound to die away. The higher the pitch the more divergent became the results obtained from their observations. For a vibration frequency of 121 they differ in minimum audible intensity by only 4 per cent., while for 1021 one is twice as much as the other. Moreover, the differences are not uniformly in the same direction. The mean values are as follows: For frequency of 121, 5.7×10^{-5} ergs are needed per second per square centimetre to produce the sensation of sound. For 246, 2.7×10^{-8}; for 493, 3.6×10^{-9}; for 1021, 9.0×10^{-10} ergs. These results in general lie between those of Fletcher and Hegel on the one hand and the final work of Wien on the other. G. F. S.

Compositions and Properties of the Commercial Arsenates.—Immense amounts of arsenic compounds are used in spraying plants for protection against insects and fungi. In 1920 over 11,000 tons of arsenous oxide were produced in the United States, more than half of which was used in the manufacture of insecticides. The principal compounds used for such purposes are arsenates, those containing lead, zinc, calcium and magnesium being the most important. An elaborate study of the composition and properties of the commercial forms has been made by F. C. Cook of the Bureau of Chemistry and N. E. McIndoo of the Bureau of Entomology. The results appear in Bulletin 1147 of the Department of Agriculture. The investigation included experiments on feeding larva with materials impregnated with arsenic. Considerable difference was found in the susceptibility of different species. The maximum amount of arsenic (As) required to kill a honeybee is 0.0005 mg., but the toxic dose for a full-grown silkworm is 0.0273 mg. It is to be noted, however, that the honeybee, confined in cases, retains the whole of the arsenic compound taken, whereas the silkworm expels most of it. Lead arsenate is one of the most used compounds. The common form, $PbHAsO_4$, is well standardized and stable. The commercial calcium arsenate contains more calcium than is required for a strictly tribasic salt. A sample of copper barium arsenate, made in the laboratory, was found to have strong insecticide properties. H. L.

Atomic Weight of Gallium.—THEODORE W. RICHARDS and WILLIAM M. CRAIG, of Harvard University (*Jour. Amer. Chem. Soc.*, 1923, xlv, 1155-1167), have determined the atomic weight of gallium by the analysis of gallium chloride, and have obtained the value 69.716. J. S. H.

Work in 1922 of the Department of Terrestrial Magnetism, Carnegie Institution, L. A. Bauer, Director. Any citizen of the United States who is conversant with the fine scientific work conducted under the direction of Doctor Bauer cannot fail to experience great satisfaction that our country is continuing to make this important contribution to the solution of the problems of terrestrial magnetism.

The *Carnegie*, the non-magnetic oceanic observatory, reached Washington in November, 1921, and is now ingloriously berthed at a wharf. This vessel has a total of 253,320 miles to its credit and observations so numerous as almost to need the integral calculus for their summation. When the department first began its work on the seas errors in declination were disclosed amounting to even as much as 16°. "Errors in inclination not infrequently amounted to over 10° and the values of the earth's magnetic intensity were found erroneous at times by amounts reaching and even exceeding 10 per cent." In spite of the long voyages of this vessel and of its predecessor, the *Galilee*, it is still stated that there are from 500,000 to 1,000,000 square miles of ocean area where no recent accurate magnetic observations have been made. The outstanding need for the future, however, seems to be a study of the variations of terrestrial magnetic elements with time. It is rather discouraging to learn that the United States Coast and Geodetic Survey reports that the rate of change of the direction of the compass "has varied so much recently that values carried forward from 1915 are in some cases not dependable."

While the observers were not on duty on the *Carnegie* they were employed in various quarters of the globe. The list of places where the department carried out observations in 1922 is an astounding one—Egypt, Tunisia, Sinai Peninsula, Singapore, Canton, Asia Minor, Syria, Islands of Eastern Mediterranean, Arabia, Siberia, Western Australia, New South Wales, New Zealand, Greece, Constantinople, Miami (Fla.), Venezuela, Brazil, Argentine, West Indies, Bahamas, the Solomon Islands and New Guinea, and several countries of Europe. Mr. Coleman used a copra-trading schooner to reach the Marquesas and the Tuamotu Islands in the Pacific.

A conference for planning future work was held in January, 1922. Among the recommendations made were the following, that magnetic and electrical observations be made in the upper levels of the atmosphere, that "because of the unsatisfactory distribution of magnetic observatories in the Southern Hemisphere, the complete program of work in terrestrial magnetism, atmospheric electricity, earth-currents and allied observations at the two magnetic observatories (Watheroo, Western Australia, and Huancayo, Peru) be fully carried out," that laboratory investigations be conducted on such subjects as the development of instruments, experimental reproduction of observed cosmic and magnetic phenomena and general magnetism and that theoretical studies be made of the results of previous analyses,

of line-integrals and of "possible bearings on the properties and constitution of matter." As typical of the kind of experimental work done in the laboratory may be cited the establishment by S. J. Barnett of the fact that a piece of iron when rotated becomes a magnet. "Rotating any ferromagnetic substance investigated at one revolution per second is equivalent to placing it in an axial magnetic field with intensity -3.5×10^{-7} gauss, within about one part in ten."

Here is one field of physics that abounds in adventure in its observational side and who can predict what a flood of light will come with the finding of the cause of the magnetism of the earth?

G. F. S.

Distillation of Water for Municipal Supply.—In the course of a communication on the water supply of the Antofagasta Railway, Robert M. Fox, Chief Engineer of the Waterworks of Delagoa Bay, refers to several phases of construction that are of importance in practice. The Antofagasta Railway links the interior of Bolivia with the Pacific coast. It was originally constructed to connect certain nitrate deposits with the port, and was a narrow gage line about twenty-two miles long. It now has a total length of over 1200 miles and crosses the mountains at an elevation of about 13,000 feet. The region in which the nitrate earth (caliche) is found is about thirty-four miles wide, extending along the coast for sixty-six miles. It is entirely rainless. The scarcity of water occupied the attention of railway authorities as soon as the extension of the track began. Even in the extension to La Paz only one river is crossed (twice) and one of its tributaries. At the beginning of operations the company depended on water distilled from sea water at the coast. Pipe lines were afterwards extended to more suitable supplies than that afforded by a river—San Pedro—which had a high degree of hardness, and the following sources are now in operation:

San Pedro River	10,712	feet above sea level
Palpana springs	11,000	feet above sea level
Polapi springs	12,486	feet above sea level
Siloli stream	14,154	feet above sea level

The last three sources are potable. The San Pedro water is not used for drinking or boilers, but for the lixiviation of the caliche. The details of construction and operation of the pipe lines and other accessories of this supply system are given in the paper, published in the *S. Afr. Jour. Sci.* (1922, xix, 120). One point deserves special notice. The company fearing that a breakdown of the pipe line supply might occur, by which a large population would be without water, set up two sextuple sets of multiple distilling apparatus with a capacity of 44,000 gallons (presumably Imperial gallons of 10 pounds) per day. These have been operated at what seems a high fuel

efficiency, a ratio of thirty pounds of water per pound of coal having been obtained. Welsh coal (approaching anthracite) has given the best result. Briquetted fuel and Australian coal have less heating power. Proper comparison, however, cannot be made without statement of the analysis of the respective samples. Oil has been substituted in a multiple distilling apparatus set up at a seaport about forty-five miles from Antofagasta, which has been in satisfactory operation for seven years. The ratio of oil burnt to water obtained has been 1 to 36. Moreover, although the cost of oil is nearly the same as that of coal, only two men are required for the oil furnaces while eight are needed for serving the coal. H. L.

ON February 27, 1923, the British Science Guild held a meeting in the Mansion House, London, in order to direct attention to the claims of research and progress in science to be matters of national import. Sir J. J. Thomson emphasized the need of methods of bringing scientific matters to the attention of large masses of the population so that legislative enactments for the benefit of science could receive public support. The neglect of men of science "was vigorously pressed by Sir Ronald Ross. It might be supposed that the discoverer of the cause of cancer or tuberculosis would soon become a millionaire, but he pointed out that Sir David Bruce, who solved the problem of sleeping sickness, was now in Madeira unemployed, and there were three or four others whom he could name. He suggested that the nation should pension scientific discoverers of preëminent worth, and allow them to go on working as they pleased."

It may be a wholesome, though a disagreeable, discipline for us Americans to demand of ourselves an answer to the question, "Which would receive the greater recognition among us, an actor in a new, popular film, or the man who should find a means of reducing tuberculosis to the comparative insignificance of smallpox?" G. F. S.

Conversion of Methyl Chloride into Methanol. RALPH H. MCKEE and STEPHEN P. BURKE, of Columbia University (*Ind. Eng. Chem.*, 1923, XV, 682-688), have studied the conversion of methyl chloride into methanol (methyl alcohol). This conversion is not produced by steam at a temperature of 350° C., even in the presence of silica, zirconium dioxide, anhydrous aluminium chloride or anhydrous calcium chloride. Aluminium hydroxide is not suitable as a catalyst since it dissociates into the oxide and water. Calcium hydroxide is an excellent catalyst; with the exception of a small amount of methane and hydrogen, the methyl chloride is practically quantitatively converted into methanol and methyl ether; less than 0.1 per cent. of the methyl chloride is converted into formaldehyde. A slight deposition of carbon on the catalyst occurs; at a temperature of 350° C., the catalyst becomes gray, at 450° C. black; as the concentration of water vapor in the gaseous mixture is increased, the deposition of carbon is noticeably decreased. J. S. H.

The Heat of Vaporization of Neon. E. MATHIAS, C. A. CROMMELIN and H. KAMERLINGH ONNES. (*Comptes Rendus*, April 3, 1923.)—Using data determined in the cryogenic laboratory of the University of Leyden, where recently a temperature only a fraction of a degree above the absolute zero has been attained, the authors have calculated the value of L, the heat of vaporization at the critical temperature, for the monatomic gas neon. In the table T represents the critical temperature.

Gas.	T Absolute Degrees.	L Calories.
Oxygen	154.29	50.06
Argon	150.65	38.10
Nitrogen	125.96	47.9
Neon	44.38	20.8
Hydrogen	33.18	106.5

G. F. S.

"I SHOULD like to emphasize that there has seldom, if ever, been such an interesting period in the history of physical science as the present time. It was a great shock to the scientist to find that the velocity of light was independent of the motion of the observer. Some explained it by saying that the earth dragged the ether along with it, but this is contradicted by the phenomenon of the aberration of light. Fitzgerald and Lorentz suggested independently the contraction hypothesis which gives a rational explanation, but which is very difficult to verify by experiment. The relativity theory does not explain the nature of the phenomenon, but it indicates that the hypothesis of the ether is not a necessity. So many exciting problems have arisen in recent years that Rutherford's experiments showing the transmutation of gases have not received the attention they deserve. These experiments mark a new epoch in the history of science, and in the future they may have marvellous commercial developments. The further our knowledge of physical science extends the more closely does it affect us in our normal everyday mental and physical life. A country that neglects the study of physical science cannot take a leading place among civilized nations." (From the presidential address of Dr. Alexander Russell to the Physical Society of London, Oct. 27, 1922.)

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